MAN AND OTHER LIVING THINGS

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AN INTRODUCTION TO HUMAN BIOLOGY

BY

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FOREWORD

THE influence of biology on agriculture, food, and health demands that the principles of general biology and the story of biological research should be widely known. Yet there are still many secondary schools in which biology is not a compulsory subject, and in many schools the syllabus of biology is restricted to a study of the anatomy of selected plant and animal types.

The reader of the present book will find in it some accounts of topics which are not at present included in the syllabus of any elementary examination. I have not hesitated to mention cases where biology has directly influenced human lives, or where the history of a discovery illustrates scientific method. Nevertheless, examination requirements have been kept strictly in mind, and, to the best of my belief, this book contains the subject-matter demanded by the examiners of the General Science Biology Courses of the School Certificate Examinations.

Some teachers may wish to modify the sequence of the material which follows, and I have therefore subdivided the chapters into sections which are to some extent complete in themselves. The omission of any section would not greatly affect the main theme of the book, which attempts to present biology as a cultural subject that forms a link between the more exact sciences of physics and chemistry and the studies of geography, history, and economics.

However, as Professor Hogben has pointed out, "Increasing recognition of the cultural value of biological study carries with it both dangers and opportunities." There is some danger that a broader field of study in biology will result in sacrifice of accuracy, and that biology may become a study in which the pupil will memorize a number of imperfectly understood generalizations. For, as Goldsmith wrote, "We should teach them as many of the facts as possible and defer the causes until they seem of themselves desirous of knowing them."

In practice, therefore, I hope that this book will be preceded by, or accompanied by, the study of animals and plants in their natural surroundings, and that whenever possible an opportunity for handling the specimens will be provided. I believe that the training in careful observation and accurate description is an

important part of the educational value of biology. Moreover, additional reading is often desirable, and to this end I have included a bibliography which I hope may prove to be helpful.

I am very grateful to all those who, whether by their encouragement or by their criticism, have directly or indirectly helped me during the preparation of this book.

I have had some opportunity of testing the value of the approach and the material of the present book, for it is based on a course of instruction which has been followed at Marlborough College during the past five years. In practice the course was designed to cover one year, comprising one or two forty-minute lessons each week. Each chapter corresponds approximately to one week's study. Many of the pupils, whose ages ranged from fourteen to seventeen years, would otherwise have received no instruction in biology during their secondary school career. In consequence, the text refers to a wide range of topics in order to stimulate a desire for further knowledge. I am indebted to my pupils, who, by their reactions to the course, have influenced the arrangement of this book.

ACKNOWLEDGMENTS

THE writer of a text-book must draw information from many sources, and it is not always possible or desirable to render full acknowledgment in the text. I should like therefore to acknowledge here particular instances of help which I have received in the preparation of certain sections of the present book.

I have been greatly assisted in the preparation of Chapter XXVI by the advice given to me by T. K. Penniman, M.A., Curator of the Pitt Rivers Museum, Oxford. This chapter owes much to the expert criticism of Mr Penniman and to that given by my father, who is responsible for the section on flint implement technique. The information in Section 3 of Chapter XVI has been partly derived from *The Uniqueness of Man*, by Julian Huxley (Chatto and Windus, 1941), and *Possible Worlds*, by J. B. S. Haldane (Chatto and Windus, 1927); these books are included in the bibliography given at the end of this book. I am grateful to Dr E. F. Griffith for his very helpful criticism of Chapter XVIII.

I am greatly indebted to Gaumont-British Instructional Films for the many photographs taken from their films and used as plates, and to Miss Mary Field for her interest and help in the preparation of these illustrations. Plates 1 (A), 11, 13, 14, 15, 16, and 28 (B) are taken from some of the Gaumont-British Instructional Films which are listed at the end of this book. I also owe a great debt of gratitude to the following for photographs and engravings: Mr S. Savage and the Linnean Society for Plate 3, the British Council for Plate 4 (A), the City of London School for the material depicted in Plates 6 (A, C) and 12, Dr N. F. Hallows for Plates 7 and 8, Dr John R. Baker for Plate 9 (B, C), Messrs May and Baker for Plate 10, Mr R. B. Pilcher, O.B.E., for Plate 20 and Plate 30 (A, B), the United Dairies, Ltd., for Plate 22, the Medical Research Council for Plates 23, 26, and 27 (B, C), Imperial Chemical Industries and the journal *Endeavour* for Plate 24, Mr J. W. Vince, of Usher's Wiltshire Brewery, for Plate 28 (A), and the Hope Department of the University of Oxford for Plate 32 (A).

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I owe a great debt of gratitude to Dr Joan Evans for her expert help in the preparation of the index.

Last but not least I am greatly indebted to the many helpful suggestions and criticisms given by my friends and pupils, to my laboratory assistant, C. Hughes, who took the photographs for the plates not already mentioned and helped me in other ways, and especially to the editorial staff of my publishers, George G. Harrap and Co., Ltd., for their unfailing courtesy and their painstaking efforts to ensure that this book will be free from errors.

F. G. W. K.

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PART I

CHAPTER I

BIOLOGY

"Where shall I begin, please your Majesty?" he asked. "Begin at the beginning," the King said gravely, "and go on till you come to the end: then stop."

LEWIS CARROLL, *Alice in Wonderland*

WHAT is biology and why should it form a part of our education? An answer to these questions will serve to introduce this text-book of general biology.

Biology is that branch of science which deals with the structure, the activities, and the history of all living things, including ourselves. We see at once that biology, thus defined, must directly or indirectly include a study of our food, of our health, and of many other influences in our lives. We shall find that by studying animals scientists have learnt much about mankind.

It may perhaps surprise you to discover that the study of a small animal, as, for instance, an earthworm, can bear any relation to the study of man. Yet it is the same type of chemical substance which colours our blood and that of the garden worm. Or perhaps you may wonder whether there can be any practical value in the study of the development of a fish. Yet when you reach page 293 you will find that the early (embryonic) stages of fishes and men are surprisingly similar. We even possess gill-clefts in our throats when we are very young, which are not unlike the gill-slits of a fish. The study of animals is closely related to the study of man. It is important to realize, however, that very many of the discoveries in biology which have conferred the greatest benefit on mankind were made by men who were interested in knowledge and discovery for their own sake, and not for the practical advantage which they might offer. Indeed, the practical benefits of a new development in science are often not apparent at the time of discovery, although in time they may have far-reaching effects.

Even the destinies of nations have been affected by seemingly insignificant little animals. For instance, the Negro republic of

Haiti owes its foundation to the help of a species of mosquito! In 1801 Napoleon sent a force of 25,000 men to quell a revolt of the Negro population on Haiti; but of this army 22,000 died because they were bitten by mosquitoes infected with yellow fever viruses. The remnants of the frightened army retreated to France, leaving the Haitians independent. Yellow fever almost stopped work on the construction of the Panama Canal, until biologists discovered methods whereby the mosquito which carried the disease could be controlled.

These are but some of the practical considerations which illustrate the value of biology in our lives. The increased enjoyment of our surroundings which is stimulated by an interest in the lives of other animals and of plants is another important aspect of biology. Biology as a science promotes and directs powers of accurate observation and provides a framework of knowledge into which the observed facts may be fitted. Above all, "Science is a method and not a collection of facts," so let us begin with a study of some of the apparatus and methods used by biologists.

1. Description

Careful and accurate description of animals and plants is the first essential in biology. The description must be concise, yet it must be easily understood by other scientists in other countries.

In medieval times the languages of Latin and Greek were the languages of scholarship, and in that sphere were universally understood. Most of the terms which we use to describe the structures of living things and their activities are therefore derived from Latin or Greek origins. Thus I have before me as I write these words scientific papers in English, Italian, German, French, and Portuguese, all dealing with colours in animals. They refer to certain colour structures as chromatophores, chromatofori, chromatophoren, chromatophores, and chromatóforos respectively. All these words have a common Greek origin (Gk., *chroma*, colour; *pherein*, to bear), and refer to particular structures. The word biology is itself derived from two Greek words—*bios*, life, and *logos*, discourse.

In order to appreciate the difficulties of biological description try to imagine that you are an explorer who has discovered an animal previously unknown to science, and that you wish to send a report of your discovery to a scientific society. A number

of points must be included in your description. Some of these are summarized below:

(i) The size, shape, and colour of the specimen.
(ii) A description of the place where it lives.
(iii) How the animal moves.
(iv) Its type of food.
(v) Whether it makes any distinctive noise.
(vi) Whether there are any marked differences between the males and females of the species.
(vii) Any characteristic features in the appearance of the animal (*e.g.*, hair, scales, horns, wings, legs, tail, ears).
(viii) What other living things feed on it.
And so on.

A description based on the above points would still be incomplete unless it included also some account of the internal anatomy of the animal. In order to investigate the **anatomy** (Gk., *ana*, up; *tome*, cutting), or internal structure, of the animal we would need to use scalpels, forceps, a microscope, and other laboratory instruments.

Still further information concerning the internal activities of the animal could be gathered by employing chemical and physical methods of investigation. The study of internal activities is termed **physiology** (Gk., *physis*, nature; *logos*, discourse).

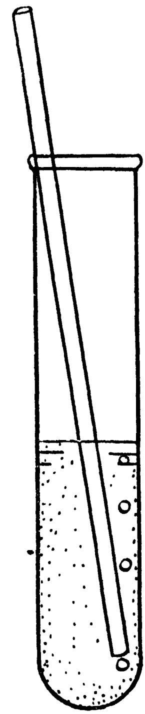

FIG. 1. DIAGRAM TO SHOW THE PRESENCE OF CARBON DIOXIDE IN BREATH

As one breathes out through the tube the lime-water in the tube becomes milky in colour.

2. CHEMICAL TESTS

As an instance of simple chemical research into an activity of living things we might attempt to find out what change occurs when we breathe in and out.

Take a test-tube containing lime-water and breathe into it through a glass tube. The lime-water will turn a cloudy colour. What is the chemical reason for this?

When we take common chalk, which the chemist calls calcium carbonate ($CaCO_3$), and heat it strongly we get lime, or calcium oxide (CaO). A gas called carbon dioxide (CO_2) has been given off. Water added to lime forms calcium hydroxide ($Ca(OH)_2$).

When we breathe into lime-water the carbon dioxide in our breath combines with the lime to give chalk once more, which forms in fine particles and clouds the lime-water:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

Yet this experiment is unsatisfactory as it stands, for it does

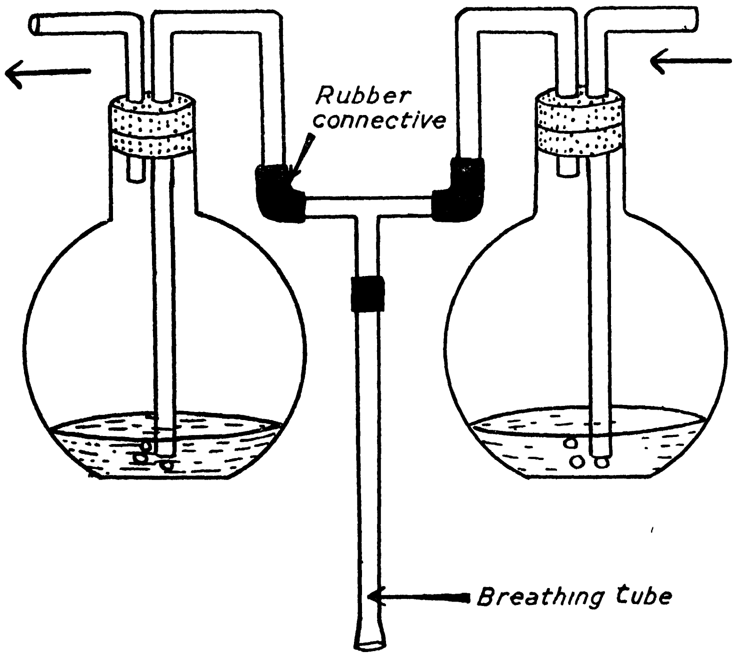

FIG. 2. EXPERIMENT TO SHOW THAT THE AIR WE BREATHE IN CONTAINS LESS CARBON DIOXIDE THAN THAT WHICH WE BREATHE OUT

Both flasks contain lime-water. Air enters through the right-hand flask and leaves by means of the left flask. The lime-water in the left-hand flask becomes milkier than that in the right.

not tell us whether we also breathe in carbon dioxide. Examine Fig. 2, therefore, and see how we may construct an experiment which also tests the air we breathe in for the presence of carbon dioxide.

This experiment may be extended to discover whether other living things also produce carbon dioxide as they breathe, and this is the experiment illustrated by Fig. 3. It can show us that earthworms, cockroaches, and even developing seeds breathe in a somewhat similar manner to ourselves, all giving out CO_2. Plants also breathe in a comparable way, as may be shown

experimentally if the plant is placed in darkness (see page 111 and Fig. 44).

These and other chemical tests give us good reason for the opinion that most of our internal activities are shared by simpler animals, and that we share some also with plants. Experiments on other living things therefore teach us about ourselves.

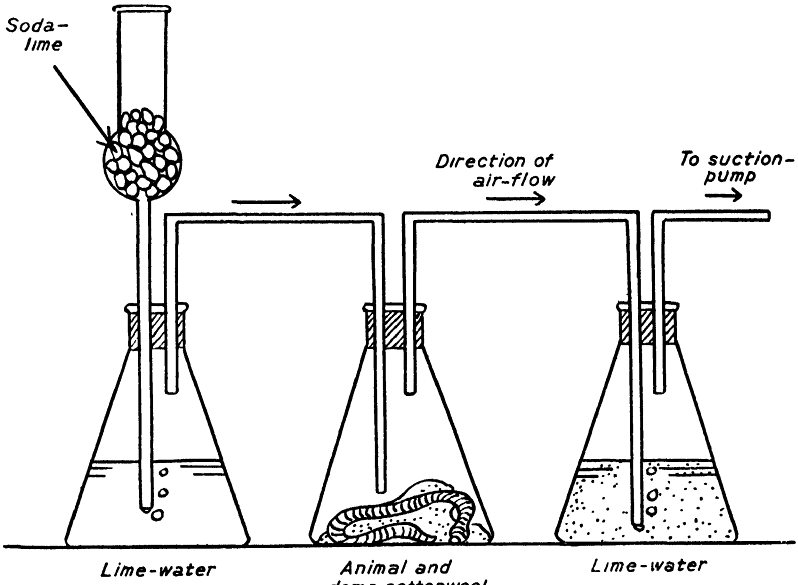

FIG. 3. EXPERIMENT TO SHOW THAT SMALL ANIMALS BREATHE OUT CARBON DIOXIDE

The soda-lime absorbs carbon dioxide, and so the lime-water in the left-hand flask remains clear. The earthworm in the centre flask breathes out carbon dioxide, and so the lime-water in the right-hand flask becomes cloudy.

3. PHYSICAL TESTS

The study of physics gives us methods and scales for the measuring of weight, volume, temperature, and movement in living things.

Measurements of volume are conducted in units called cubic centimetres, or **millilitres,** of which one thousand comprise one **litre.** One millilitre of water at 4° C. weighs one **gramme.** One thousand of these make up one **kilogramme.**

Length is measured in millimetres, centimetres,[1] and metres.

[1] 1 cm. = ·3937 inch. 1 inch = 2·54 cm.

Minute lengths are measured in **microns,** which have the symbol μ, and are equal to $\frac{1}{1000}$, or 0·001, of a millimetre.

Temperature is usually measured on the Centigrade scale, in which 0° C. is the freezing-point and 100° C. the boiling-point of water. The Fahrenheit scale, ranging from 32° F. (freezing-

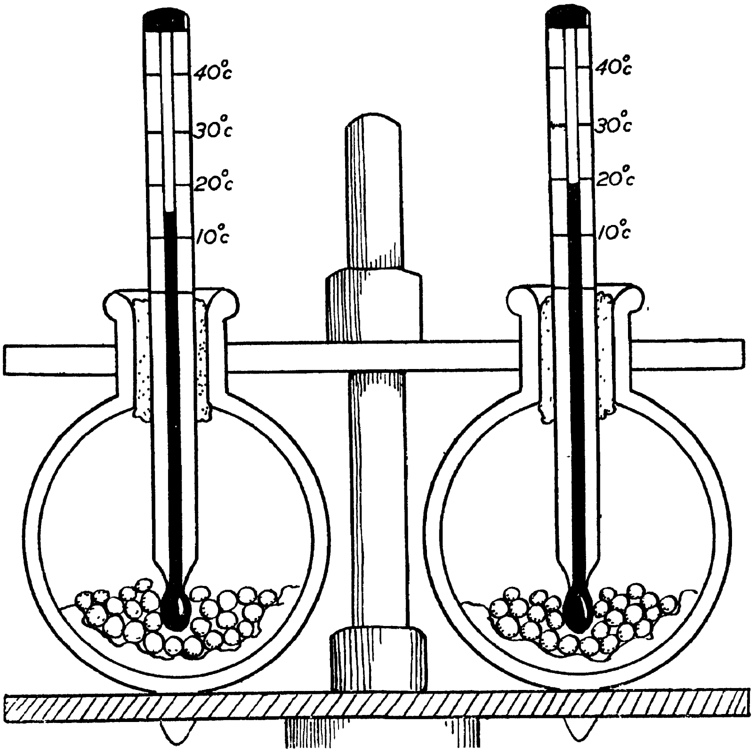

FIG. 4. DEVELOPING PEAS GENERATE HEAT

The thermos flask on the left contains dead peas, that on the right living peas, and both contain cotton-wool. As the peas in the right-hand flask develop they generate heat, and the mercury in the thermometer rises. (After two days the dead peas may decompose, and in so doing also become warmer.)

point) to 212° F. (boiling-point) is also used. Temperature tests on living things are simple and illuminating. We may easily examine our own temperature, and we would find that it is normally about 98·4° F., or 37° C., at all times (except when we are ill), although the temperature of our surroundings may be very much lower. We refer to mammals and birds as warm-blooded because they maintain a steady body-temperature, which is usually much higher than that of their surroundings;

the cold-blooded creatures, such as reptiles, amphibians, and fishes, are so called because their body-temperature is seldom much higher than that of their surroundings and varies with it. Plants can also be warmer than their surroundings. The experiment illustrated in Fig. 4 shows that young developing peas generate heat.

This experiment also shows the value of a **control,** which is such an essential feature of most biological experiments. The temperature difference between the developing peas and their surroundings is so slight that we must be sure that this temperature change is an effect of their being alive and is not merely due to the nearness of the peas to the bulb of the thermometer, or some other factor. The difference in temperature between the living and dead peas is therefore a measure of the heat which living material generates, by reason of its quality of life.

SUMMARY

(1) Living things are related to one another, and so by studying animals and plants we learn about mankind.

(2) The first stage in the investigation of an unknown animal or plant consists of accurate and concise description of its structure and activities.

(3) Methods used by chemists and physicists are employed also by biologists in their investigations on living things.

(4) Experiments on living things should include controls. Experimental animals or plants and the controls are maintained under exactly the same conditions, save for one additional experimental factor in the experimental animal or plant.

SUGGESTIONS FOR HOME STUDY

(1) Describe as completely as you can, with the help of the suggestions at p. 17, (*a*) an earthworm, (*b*) a fish, (*c*) a horse.

(2) Construct an experiment to show whether plants breathe out carbon dioxide (*a*) in light, (*b*) in darkness.

of wings are formed, but in the house-fly the hind pair of wings are reduced to a pair of drumstick-shaped appendages called **halteres** (Gk., *halter*, weight), or 'balancers.'

House-flies have wide tastes in food. At one moment a fly may visit our dining-tables and delicately drink the milk, and

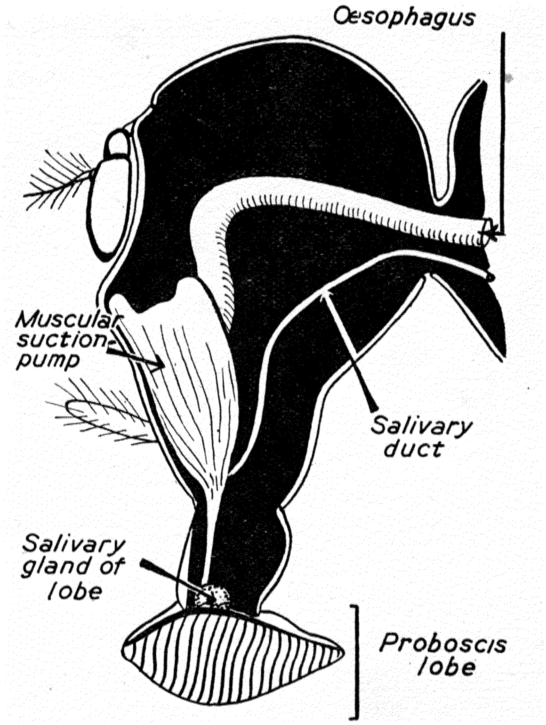

FIG. 6. HEAD OF THE HOUSE-FLY, OPENED ON THE LEFT SIDE TO REVEAL THE FEEDING MECHANISM

Redrawn after Hewitt

then return to his interrupted meal at the local refuse-dump. Nor is the fly a polite feeder, for he first spits on his food and then sucks it into his body.

When the head of a fly is examined a large **proboscis** (Gk., *proboskis*, trunk) is seen on the lower side of the head (Plate 1). As the fly feeds he lowers this proboscis until the pad-like extremity touches the food. A fluid produced by **salivary glands** (Gk., *saliva*, spittle; L., *glans*, acorn) in the head is then emitted on to the food and makes it liquid. As the food becomes fluid it is sucked by a muscular pump into the body of the fly.

During its life a fly breathes by a mechanism which differs greatly from the breathing apparatus in ourselves. If you examine a fly with a powerful lens (Plate 6) you may see a number of fine breathing-pores, called **spiracles** (L., *spiraculum*, air-hole), on the sides of the body. Air passes into the body through these pores and circulates through a fine network of tubes, called **tracheæ** (Fig. 45) (L., *trachia*, windpipe). These communicate with large

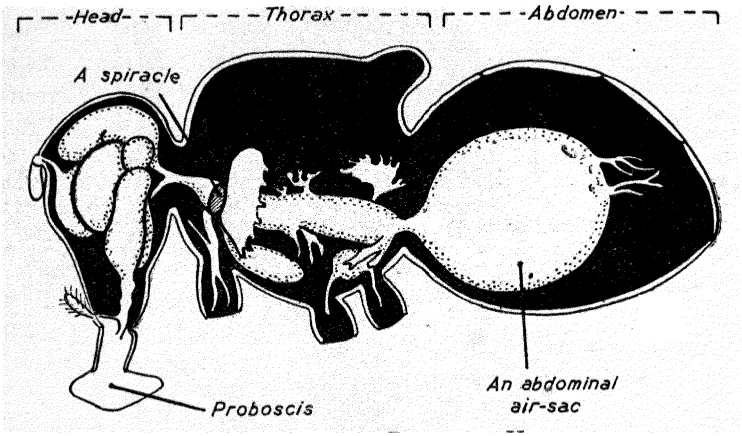

FIG. 7. AIR-SACS IN THE BODY OF A HOUSE-FLY

The fly has been opened on the left side and the main sacs shown. All other internal organs and some of the air-sacs have been omitted for the sake of clarity.

Redrawn after Hewitt

air-sacs in the abdomen, thorax, and head, which probably give buoyancy to the animal and so assist its powers of flight. The tracheæ and air-sacs altogether occupy more space in the body of the fly than any other set of organs.

Two large eyes give the fly a wide field of vision. These eyes, called **compound eyes,** consist of about four thousand separate parts, each provided with a lens, and with a light-sensitive portion which can perceive a section of the field of view (see Plates 1 and 17). The separate images formed by the distinct parts of the eye together form an image of the surroundings of the fly. The lenses, unlike those in our eyes, cannot foçus, and hence the fly probably cannot perceive objects distinctly. Compound eyes, which are found in most other insects, are therefore, in spite of their apparent complexity, less effective in some respects than our own eyes (p. 154), though probably they are quick to perceive movement in the external field. In addition to its two large compound eyes, the fly bears three tiny eyes (*ocelli*) on the top

of its head, which probably distinguish little more than light or darkness.

If the windows on which flies have rested are examined carefully brown specks may be seen. These spots are made up of waste material which has been expelled, or **excreted** (L., *ex*, out; *cernere*, to sift), from the body of the fly.

Male and female flies mate and produce large numbers of

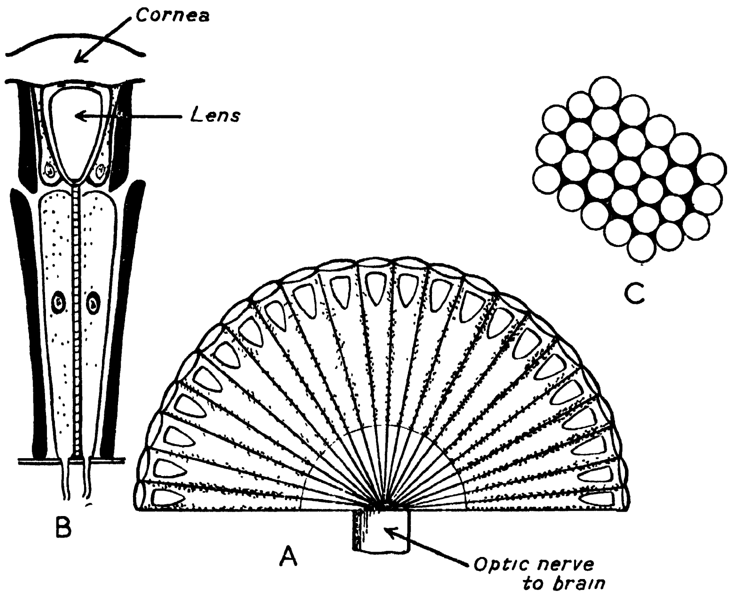

FIG. 8. DIAGRAMMATIC VIEWS OF THE EYE OF A HOUSE-FLY

A, section through the centre of the eye, showing the many separate units which form each eye; *B*, parts of a single unit; *C*, surface view of a small portion of an eye.

young. In the male the space between the eyes occupies one-fifth to one-quarter of the head, while in the female fly it is broader, comprising almost one-third of the head. If the abdomen of a female fly is cut open in the summer it will be seen to be almost filled with eggs.

2. THE DEVELOPMENT OF THE HOUSE-FLY

When the female house-fly has mated with the male she proceeds to lay great numbers of eggs, which will in time develop to form new flies. Development proceeds in four distinct stages, which follow one another slowly or rapidly, depending on the

temperature. The durations of the stages given below are therefore only approximations.

Stage 1. The Egg (Plate 2).[1] The female fly lays eggs, in batches of about 120–150, on any decaying material which will serve as food for the developing young. Rubbish-dumps, old

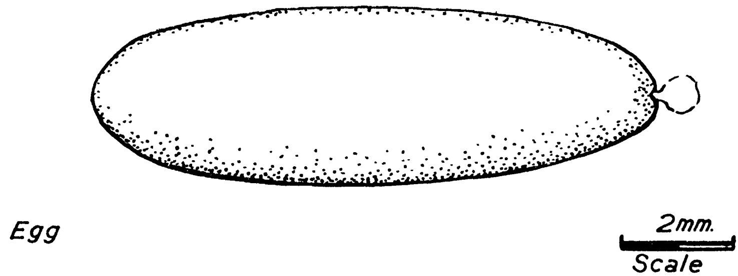

FIG. 9. EGG OF THE HOUSE-FLY

bread and cakes, rotten fruit or meat, all provide good breeding-grounds for flies.

Stage 2. The Larva (Plate 2). After a day or two white, worm-like, legless maggots emerge and feed. These maggots are an example of what are known as **larvæ** (L., *larva*, ghost). These

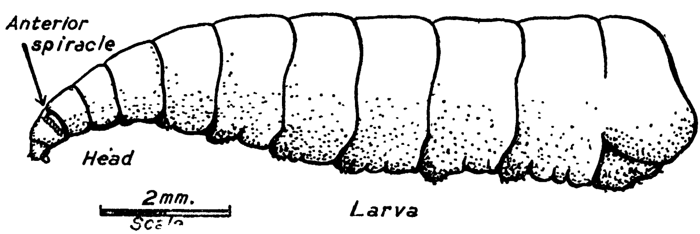

FIG. 10. LARVA OF THE HOUSE-FLY

larvæ move by the aid of a hook on the head and a series of spiny pads on the lower surface of the body. They are sensitive to light and move away from it. They feed voraciously and grow rapidly, becoming fully grown in about five days in hot weather.

Stage 3. The Pupa (Plate 2). When the larva is fully grown it becomes covered with a hard case and forms a **pupa** (L., *pupa*, puppet), or **chrysalis** (Gk., *chrysos*, gold). This is first red,

[1] The stages in the development of the blow-fly, shown in Plate 2, resemble the comparable stages in the house-fly in appearance, though not in size (see Figs. 9, 10, 11).

later brown, and finally black. Within this case the larva changes into the adult fly.

Stage 4. The Adult (Plate 2). After from three days to four weeks the transformation is complete, and the adult fly bursts the pupal case by alternately inflating and contracting an air-sac (the ptilinum) in the head region.

When the fly emerges it is almost fully grown, and does not increase greatly in size during the rest of its life.

In hot weather flies may lay eggs about three weeks after they themselves commenced their life-cycle as such. Since females

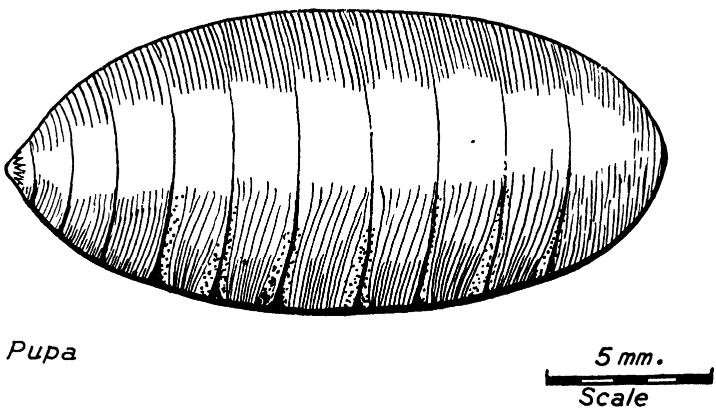

FIG. 11. PUPA OF THE HOUSE-FLY

lay about six batches of eggs a single fly may produce between 600 and 900 eggs.

One authority has calculated that the descendants of a single fly, which deposited her eggs on April 15, might number 5,598,720,000,000 by September 10 of the same year, supposing that the weather was warm, that all the eggs laid became adults, and that there were no checks on their multiplication.

3. VARIETY OF FLIES

Most of the flies which live in our houses belong to the species which the biologist calls *Musca domestica*,[1] or house-fly. There are, however, other species of flies in our houses, principally *Fannia canicularis*, or the lesser house-fly. Less frequently stable-flies and blow-flies, or bluebottles, are found.

[1] The significance of these Latin names is discussed in Chapter V.

Collections of flies made at various towns in Britain have shown that more than four-fifths of the flies found in houses are of the species *Musca domestica.*

LOCALITY	NUMBER COLLECTED	PERCENTAGES OF SPECIES		
		Musca domestica	*Fannia canicularis*	*Other Species*
London . .	35,000	81·0	17·0	2·0
Manchester. .	3,856	87·5	11·5	1·0
Birmingham .	24,562	91	4·7	4·3

It is interesting to collect some of the flies in rooms and to examine the differences which separate the species. The lesser house-fly is distinguished from the common house-fly by a number of small differences, chiefly by its smaller size and the patterns of the veins on the wings (Fig. 12).

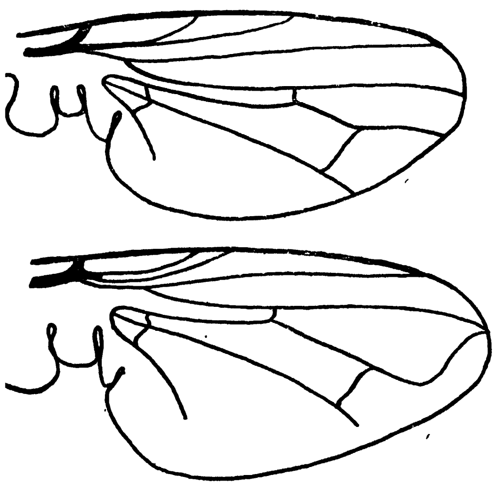

FIG. 12. DIAGRAMS SHOWING DIFFERENCES BETWEEN TWO SPECIES OF HOUSE-FLY
Above is the right wing of *Fannia canicularis* and below that of *Musca domestica.*

The stable-fly (*Stomoxys calcitrans*) is about the same length as the house-fly, but is broader; it is a blood-sucking insect and has a shining black pointed proboscis projecting in front of the head.

The blow-fly, or blue-bottle (*Calliphora erythrocephala*) (Plate 2), is much larger than the house-fly, and is easily distinguished by the persistent buzzing noise which it makes as it flies.

4. FLIES AND OTHER LIVING THINGS

Many of man's diseases are caused by 'microbes,' which travel from a diseased person to a healthy one (Chapter XX). Flies feed indiscriminately on sewage, refuse, and the food on our

tables. Hence it is not surprising to find that they may affect mankind by acting as carriers of microbes which cause disease.

Their habit of spitting on their food before they absorb it allows them to suck disease microbes from sewage or refuse, and later to spit them on the food which we eat. Microbes also cling to the hairs on their legs. In tropical countries, where sanitation is poor, flies abound, and spread many dangerous diseases, including cholera, typhoid, and dysentery. In England their influence is less, but they are known to transmit the disease called 'summer diarrhœa,' which kills large numbers of infants each year.

Flies have many enemies which prey on them; some are other insects, others are mites, tiny worms, and minute animals called **protozoa** (Gk., *protos*, first; *zoa*, animals) (Chapter XXI). The most important enemy of the house-fly, however, belongs to a type of living organism called a **fungus** (Chapter XXII).

In the early autumn many dead flies will be found on the window-panes, walls, and ceilings. If you look at one of these with a lens you will see that its body is swollen, and that white bands occur between the **segments** (L., *segmentum*, piece) of the abdomen. These are signs of a fungus called *Empusa muscæ*, an organism with a body composed of threads, which penetrate into the body of the fly and kill it.

We do not know exactly where house-flies spend the winter. Probably most of those which survive the attacks of Empusa crawl into cracks in the wall or other warm places and sleep there until the following spring.

5. The House-fly as a Representative Animal

A study of the house-fly shows that it performs many of the activities which operate also in our lives. Like the house-fly, we grow, develop, feed, move, breathe, excrete, respond to our surroundings, and reproduce our kind. If you consider some of the other animals familiar to you you will realize that most if not all of the activities enumerated above are performed by all animals; in fact, they are usually cited as the qualities which distinguish living organisms from non-living things.

But the study of the anatomy of the house-fly shows that although animals share certain activities the organs by which they may perform these functions often differ greatly in form.

We, for instance, have internal skeletons made of bones, but the house-fly has a skeleton which covers its body; our development differs greatly from that of the fly; our eyes are very different. These and many other differences show that while animals have a perfection of structure which fits them for their requirements and habits they are often built in very different ways.

SUMMARY

(1) The study of the life of the house-fly shows that, like ourselves, it grows, develops, feeds, moves, excretes, breathes, responds to its surroundings, and reproduces its kind.

(2) There are a number of distinct types, or species, of fly, which nevertheless resemble each other in their general appearance.

(3) House-flies carry the germs which cause some human diseases; they are themselves attacked by various living things.

SUGGESTIONS FOR HOME STUDY

(1) Describe, with large and clearly labelled drawings, the structure and the life-history of a house-fly. How would you distinguish between *Musca domestica* and the other species of house-fly?

(2) In what ways does a house-fly (*a*) resemble, (*b*) differ from, ourselves?

CHAPTER III

THE MEADOW BUTTERCUP: A REPRESENTATIVE PLANT

Fix'd like a plant on his peculiar spot,
To draw nutrition, propagate, and rot.
A. POPE, *An Essay on Man*

WE instinctively associate life with movement, yet the flowering plants, which do not move as a whole, although parts of their bodies may alter in position, are nevertheless living things. Though they are stationary they perform most of the activities of a living animal, but in different ways.

The common meadow buttercup will serve to illustrate the main features of a plant. The majority of flowering plants do not differ very greatly from one another in their general plan of structure or in their activities, and the description of the anatomy and activities of a buttercup is therefore also applicable in the main to many other plants.

1. THE ADULT PLANT

The branched and spread-out body of a buttercup, its lack of movement and its green colour are in contrast with the active and compact house-fly. Yet, in spite of their irregular shapes, flowering plants are constructed on a common plan. That part below the ground is called the **root,** while the **shoot** rises above the ground and consists of a **stem** bearing **leaves** and **flowers.**

The root serves three main functions:

(i) It anchors the plant firmly in the soil.
(ii) It absorbs water and other chemical substances from the soil.
(iii) In some plants it stores reserve supplies of food.

In some root-systems (*e.g.*, those of most trees and shrubs, of the wallflower, and of the dandelion) there is one main root, called the **tap-root,** and from this smaller roots branch. In many other plants (*e.g.*, buttercup, grasses, cereals) a number of roots, equal in size, form a **fibrous root-system.** The shoot

consists of a main stem, bearing branches, leaves, and flowers. Leaves arise at fairly regular intervals from regions of the stem known as **nodes** (L., *nodus*, knob). The leafless portions of the stem between successive nodes are called **internodes.** The angle between a leaf and a stem is called the **axil** (L., *axilla*, armpit) of the leaf, and at this point an **axillary bud** is usually formed.

Buds are young, undeveloped shoots. Branches are formed by the growth of axillary buds. If you look at a branch of the buttercup stem you will find that the branch arises at a point between the stem and a leaf (Fig. 13).

At the tip of the main shoot and of each branch you will find a **terminal bud,** which, by its growth, lengthens the shoot, or, in the case of flower shoots, opens to form a flower. In trees which persist through the winter buds remain in a **dormant** (sleeping) state on the stem after the leaves have dropped off. In the warm spring weather the buds open and grow rapidly, so covering the tree with small branches bearing leaves (Fig. 92).

Flowers do not look like leaves, but they are, in fact, built of special leaves which surround and enclose the reproductive organs of a plant. On the outside of a buttercup flower there are five green **sepals** (L., *separare*, to separate), which covered the flower bud until it opened. Inside the sepals are five yellow **petals,** each of which bears an organ called a **nectary** at its base. The nectaries contain a sugary solution called **nectar**; this, and the bright colour of the petals, attract insects to the flower. Within the petals a large number of **stamens** (L., *stamen*, warp) constitute the male reproductive organs. Each stamen bears an **anther** (Gk., *anthos*, flower), which produces very great numbers of **pollen grains** (L., *pollen*, fine flour), which are in the form of fine yellow dust. In many plant species, usually those with inconspicuous flowers, the pollen grains are carried by the wind from one flower to another (Chapter XVII). In the centre of the flower you will see a number of green **carpels** (Gk., *karpos*, fruit), each of which contains an **ovule** (L., *ovum*, egg). This latter contains a female reproductive egg-cell, and so the buttercup flower bears both male and female reproductive structures. It is therefore said to be **hermaphrodite.**

This brief description of a flower[1] completes our survey of the anatomy of a plant, and it is now time to examine the activities

[1] A more detailed account follows in Chapter XVII.

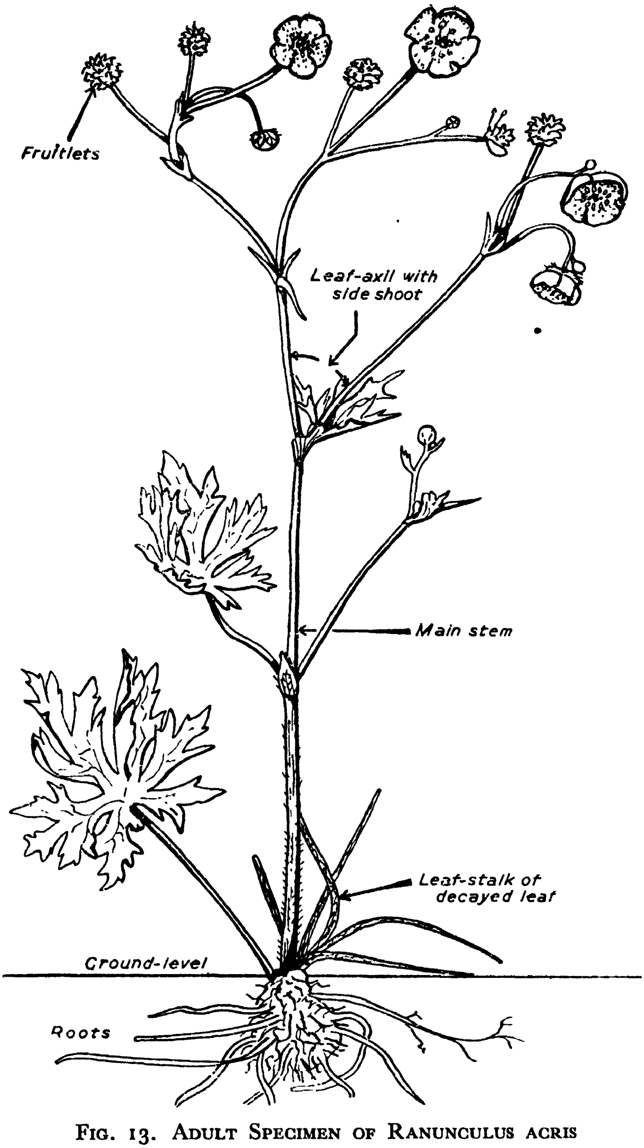

FIG. 13. ADULT SPECIMEN OF RANUNCULUS ACRIS
This figure is drawn from life, slightly less than half the natural size

of plants in order that we may compare them with those of animals.

The buttercup develops from a seed and grows until it is fully

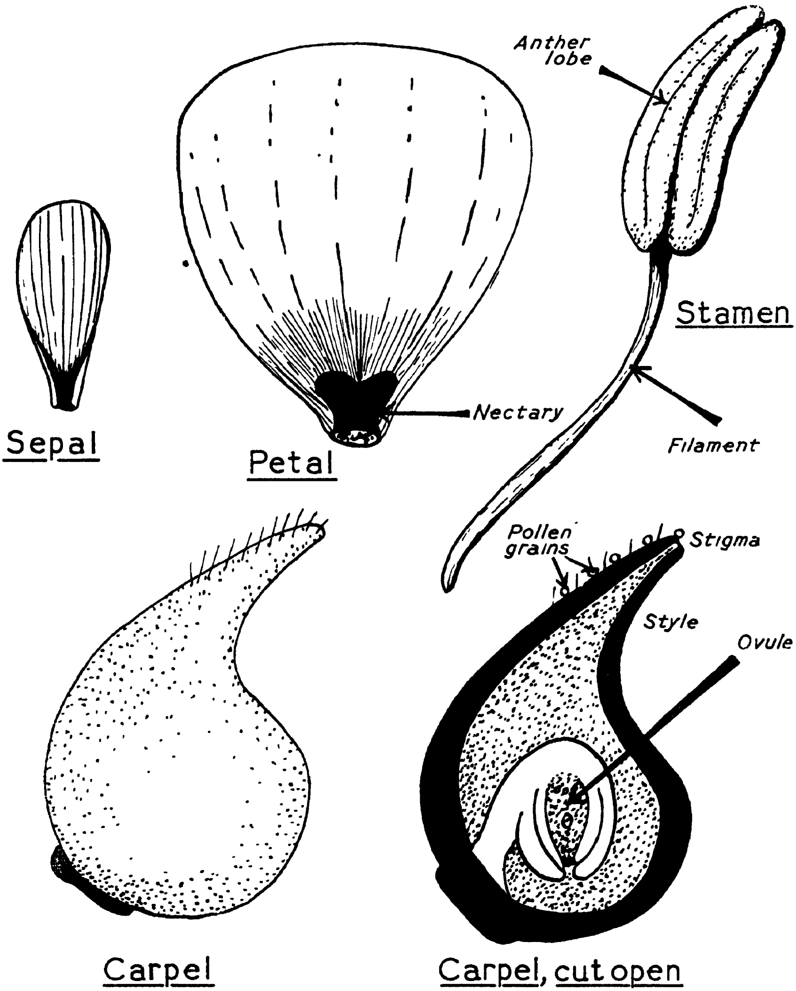

FIG. 14. COMPONENT PARTS OF A BUTTERCUP FLOWER

The stamen and carpel have been enlarged more than the petal and sepal. See Fig. 84, p. 178, for a complete illustration of a flower.

formed. For this growth to occur it is logical to suppose that plants must feed. They cannot move to obtain their food, but absorb chemical substances from the soil and the air, through their roots and leaves respectively. If we arrange plants with

their roots in pure distilled water, or if we cover their leaves with vaseline, they can no longer obtain food, and so cease to grow.

Plants do not grow normally if they are left in total darkness for some time. The absorption of certain rays in sunlight, by a chemical compound called **chlorophyll** (Gk., *chloros*, green; *phyllon*, leaf), which gives the leaves a green colour, is essential for the occurrence of their feeding processes.

We have already found[1] that developing seeds respire, much as we do. Fully formed plants also respire, but this can only be shown to occur if the plant is first placed in darkness,[2] since otherwise the plant 'feeds' on the carbon dioxide as it is produced.

Plants also respond to sunlight by bending towards it. If a plant is placed so that it is lighted from one side only it will bend towards the source of light.

2. The Development of a Plant

Plants, like animals, reproduce their kind. The buttercup effects this process with the help of insects, which pollinate the flowers by carrying pollen grains from one to another as they visit them to seek for nectar. As the insect enters the flower to reach the nectaries a number of pollen grains stick to its body as it brushes past the anthers.

When it continues its journey the insect carries these pollen grains to the next flower that it visits. Here some of the pollen grains may become transferred from the insect on to the **stigma** (Gk., *stigma*, mark) of a carpel (Fig. 14). If this should happen the pollen grain sends out a long tube which makes its way down inside the **style** (L., *stilus*, pricker) to the ovule. The contents of the pollen grain then travel down this tube and a fusion of living material from the pollen grain and the ovule takes place.

When the fusion between the materials in the ovule and those in the pollen grain is complete the carpel and its contents begin to increase in size, forming what we call a **fruitlet.** If we open this fruitlet and examine its contents with a lens we shall find that it contains a **seed,** formed from the ovule and its coverings. Inside this seed a tiny new buttercup plant has begun to form.

After some time the fruitlet becomes ripe and falls to the ground, where the seed remains without any further outward

[1] See p. 18. [2] Refer to Fig. 42 and p. 111.

change until the following spring. Then, as the weather becomes warmer, the young plant inside bursts through the seed-coat and develops into a new buttercup plant. This development of a seed is called its **germination** (L., *germen*, bud).

Germination of a seed is conveniently studied in a bean seed, which is very much larger than that of a buttercup, or in a cress seed, which is easily obtainable and resembles the buttercup seed in its development.

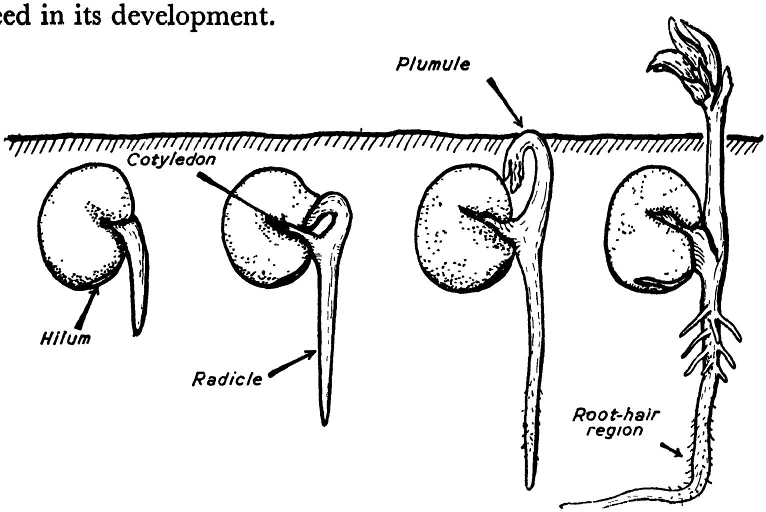

FIG. 15. FOUR SUCCESSIVE STAGES IN THE GERMINATION OF A SEED OF THE BROAD BEAN (VICIA FABA)

The beans are shown here at approximately half natural size.

When seeds of the broad bean are soaked in water they absorb it, and become larger and softer. At one end of the seed a scar marks the place where the seed was attached to the carpel wall—in this case a bean-pod. Inside the seed-coat we find the **embryo** plant. Most of the space is taken up by two large seed-leaves called **cotyledons** (Gk., *kotyle*, cut), which contain reserves of food material. Where these join we find a minute root, the **radicle** (L., *radix*, root) and a tiny shoot called the **plumule** (L., *plumula*, small feather).

When the bean is supplied with the necessary conditions of warmth and moisture it germinates. First the seed-coat splits and the radicle emerges. Next the plumule grows upward and its leaves spread out. Until the leaves form chlorophyll the seedling plant feeds on the store of food in the cotyledons, which remain beneath the soil.

Cress seeds germinate quickly if they are placed on damp blotting-paper in a dish and kept in darkness.

The cress seed resembles the bean in its germination, save in one particular. The seed-leaves do not remain beneath the ground but are raised above by the growth of the plumule, and become the first two green leaves of the plant. This type of germination is called **epigeal** (Gk., *epi*, upon; *gē*, earth) ger-

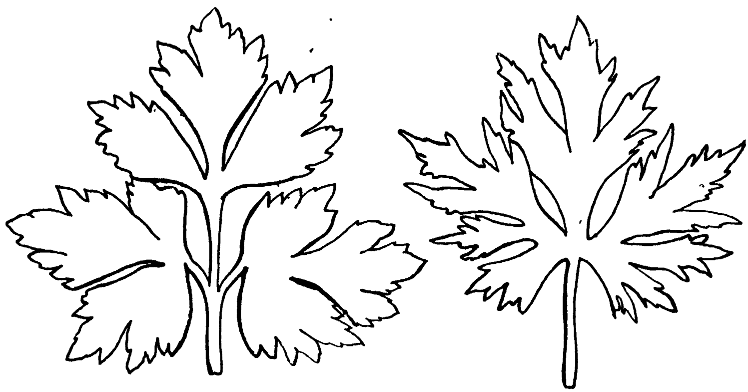

FIG. 16. THE DIFFERENCES BETWEEN THE LEAVES OF TWO SPECIES OF BUTTERCUP

This figure is one-half natural size.

mination to distinguish it from the **hypogeal** (Gk., *hypo*, below; *gē*, earth) germination of the broad bean.

3. SOME SPECIES OF BUTTERCUPS

More than one species of buttercup may be found in meadows. Three species are common, known respectively as *Ranunculus acris*, *Ranunculus repens*, and *Ranunculus bulbosus*.

Ranunculus bulbosus is distinguished by a swelling at the base of the stem at ground-level, and by the reflexing (bending back) of the sepals against a ribbed flower-stalk.

Ranunculus repens stands less erect than the other kinds; the stem is often found to be 'creeping' laterally over the ground in a fully grown specimen. *Ranunculus repens* has a furrowed flower-stalk but possesses neither the swollen stem base of *Ranunculus bulbosus* nor the latter's reflexed sepals.

Ranunculus acris is an erect plant with a smooth flower stem,

and has flowers that are slightly smaller and paler than those of *Ranunculus repens.* Like *Ranunculus repens,* it has no swollen base to the stem, neither has it reflexed sepals. The leaves of *Ranunculus acris* are more deeply divided than those of *Ranunculus repens,* but, as Figs. 16 and 17 show, any one such feature, if taken alone, is not a satisfactory guide to the identification of plants.

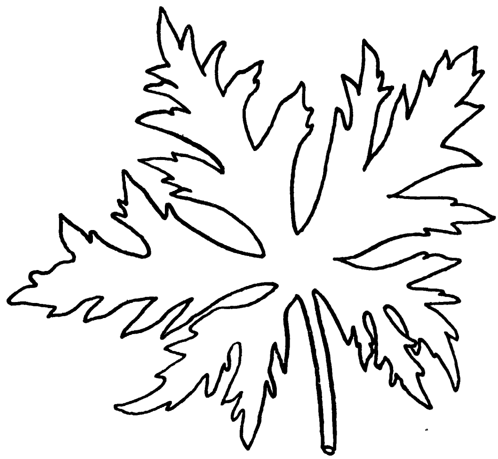

FIG. 17. LEAF OF THE MEADOW CRANESBILL
Although this plant is not closely related to the buttercup, their leaves are very much alike. This figure is slightly over one-half natural size.

4. BUTTERCUPS AND OTHER LIVING THINGS

Plants compete with one another, and buttercups have therefore a certain advantage in any meadow which is being grazed by cattle, for the cattle eat grasses and other plants in preference to the bitter leaves and stems of *Ranunculus acris.*

Buttercups are also influenced by insects, for these are necessary for their reproduction. A great variety of insects visits buttercups, and so pollination is usually effected.

Some flowers are so built that only bees or butterflies, which have long sucking mouth-parts, can reach the nectar. Consequently, if these flowers do not flourish for some reason one year near-by populations of bees will gather less nectar, and may starve in the winter unless they are fed. Conversely, if any disaster should overtake the bees or butterflies pollination may be less certain. So we find that the lives of buttercups are influenced by other plants, by the animals which eat them, and by the animals which pollinate flowers.

5. Plants and Animals Compared

To close this chapter, let us compare the lives of a buttercup and a house-fly. It is at this stage difficult to see any similarities in structure, but it appears that there are resemblances in activity or function. Both animals and plants develop and grow, they take in and make use of food, and respire, they respond to outside stimuli, and they can all reproduce their kind. Yet, in contrast, while animals can usually move, plants can seldom move their bodies from one place to another. Animals feed on chemical substances derived from other living things (the sugar, bread, and milk on which the fly fed once formed part of a plant or animal), while plants feed on simple chemical substances in the soil and the air. Moreover, plants use light in their feeding processes.

Thus, as we shall see in Chapters VI and VIII, plants obtain their energy from sunlight, while animals obtain their energy from the food which they eat. The feeding of animals is independent of light. The nutritive activities of plants are essentially building-up processes involving the intake and storage of energy: in contrast, the utilization of food by animals is a breaking-down process, whereby energy is released. These differences and similarities may be clearly expressed in a table.

COMPARISON BETWEEN ANIMALS AND PLANTS

Animals	Plants
Grow	Grow
Develop	Develop
Feed	Feed
Respire	Respire
Reproduce	Reproduce
Respond to stimuli	Respond to stimuli
Usually move	Seldom move
Feed on living or dead—*i.e.*, organic—materials	Feed chiefly on non-living—*i.e.*, inorganic—materials
Do not utilize sunlight in process of feeding	Make use of light in feeding

SUMMARY

(1) A buttercup has a body composed of a root and a shoot, the latter consisting of a stem bearing leaves and flowers.

(2) Reproduction occurs when pollen grains are carried from one flower to another by insects and reach the carpels.

(3) The fertilized ovule within a carpel forms a seed, which will later become a new buttercup plant.

(4) There is more than one distinct species of buttercup.

(5) Buttercups are influenced by other living things.

(6) Buttercups resemble animals in many of the activities which they perform.

SUGGESTIONS FOR HOME STUDY

(1) Discuss the part which insects play in the life of a flower.

(2) Compare the structure and the activities of an insect and a flower.

CHAPTER IV

THE COMPOSITION OF LIVING THINGS

Like following life through creatures you dissect,
You lose it in the moment you detect.

A. POPE, *Moral Essays*

OUR study of an animal and of a plant revealed that these living things share many activities in common. We shall now look to see whether all living things are built of like chemical substances, and whether the various forms of life are built on any common plan.

1. THE CELL THEORY

Many of the early biologists noticed that animals and plants were composed of tiny compartments, which they called **cells** (L., *cella*, compartment). They did not realize, however, that the many forms of these cells which they saw were similar in plan, so that all the diverse structures in animals and plants are built of fundamentally similar cells, just as a house is built of bricks.

In 1838 two friends named Schleiden and Schwann summarized the many observations of earlier workers on the cellular basis of living things in one great generalization, the **Cell Theory**, which asserted that all living things are built of fundamentally similar units, called cells.

M. J. Schleiden (1804–81) was for many years a professor of botany at Jena. His friend Theodor Schwann (1810–82) worked primarily on the structure of animals. While they were discussing their researches they were struck by the resemblance between the small compartments, or cells, which Schleiden had described in plants and those which Schwann had examined in animals. In both cases they noted that these cells each contained a body called the **nucleus** (L., *nucleus*, kernel), which in its development and relationship to the rest of the cell was remarkably constant in all animals and plants. Each cell was separated from its neighbours by an outer covering, the cell-membrane, or **cell-wall.**

Most cells are microscopically small. The human body is

built of more than a hundred billion cells. Red blood-cells are less than 8/1000 of a millimetre in diameter.

The Cell Theory permitted a much greater understanding of the structure of living things. For, in Schwann's own words (translated), "The great barrier between the animal and vegetable kingdoms—namely, diversity of structure—thus vanishes. Cells, cell-membrane, cell contents, nuclei, in the animals are analogous to parts with similar names in plants."

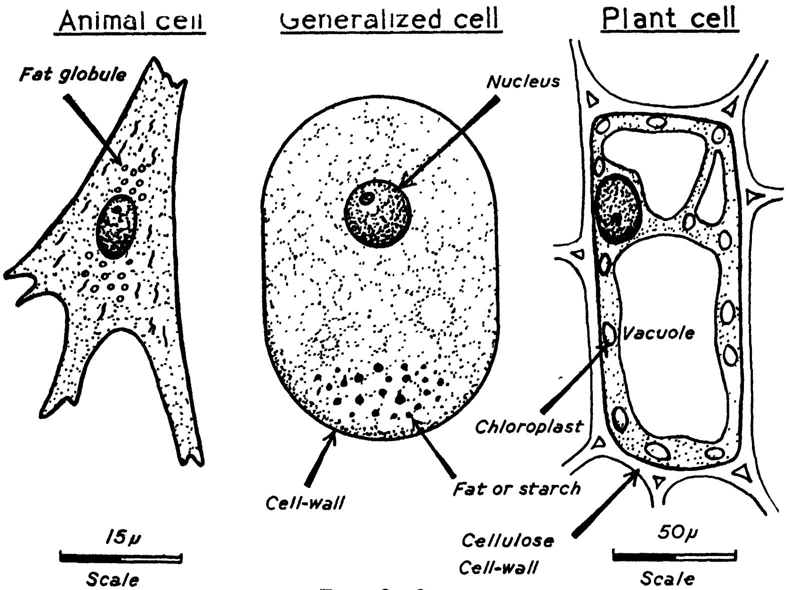

FIG. 18. CELLS

Centre, diagram to show the essential features of a cell; left, cell from human connective tissue; right, cell from the plant Canadian pond-weed (*Elodea canadensis*).

Previously the only unit of life in biology had been the entire organism, and the change in biological thought which followed the cell theory was comparable to the changes produced in the chemical and physical sciences by the concept of the molecule and the atom as units of structure. In all cases the clear definition of units of structure led to a greater precision, by revealing the common plans of structure that underlie the diverse forms both of non-living materials and of living things.

In the body most cells are specially modified for some particular purpose. For example, the cells of the nervous system, which carry 'messages' round the body, are long and thin, like wires, while the cells which line the insides of our mouths are flat, like

paving-stones (Plate 6). Muscles are built of tapering 'elastic' cells, which are capable of changing their shape. Groups of similar cells, generally with the same function, form what we call **tissues** (Fr., *tissu*, woven). Skin, muscle, and nerve are examples of such tissues. A group of tissues built on a definite plan, like the brain, heart, or lungs, is called an **organ** (Gk., *organon*, instrument).

Schwann stated that cells have lives that are to some extent

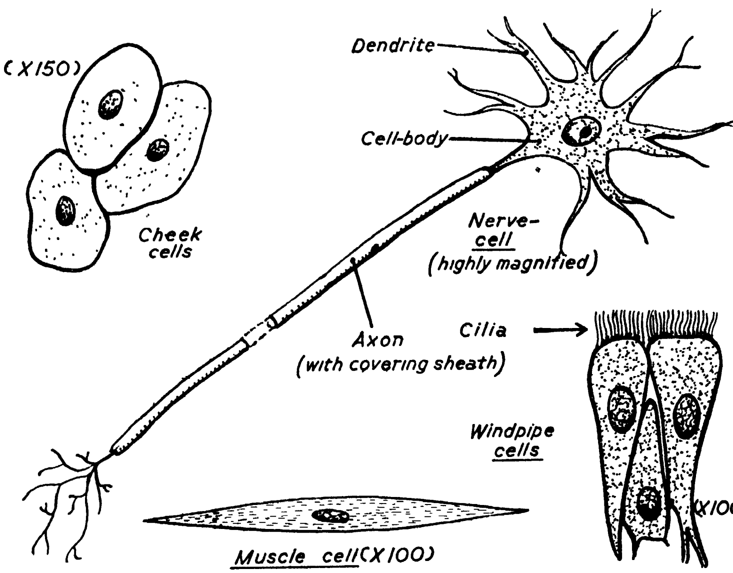

FIG. 19. CELL TYPES IN THE ANIMAL BODY

The cells shown are human cheek cells, a muscle cell from the intestines of a cat, three cells from the lining of the trachea of a rabbit, and a human nerve cell. The approximate magnification is stated on the figure.

their own, though in the body these individual lives are subject to that of the whole animal or plant. Assuming the first statement to be true, we might expect that cells could be removed from the body and yet survive.

This remarkable fact was first actually demonstrated by Harrison in 1907, when he removed small fragments of the nervous system from a frog and immersed them in a drop of blood fluid. The cells continued to thrive, and even increased in number. This method of 'tissue culture' has been greatly extended since, and is a convenient method for the study of cells. Some cells from a chicken's heart have been kept alive in New York since 1912. In 1936 they were still healthy and still growing,

and there seems to be no reason why they should not continue to live indefinitely.

When cells are grown in culture solutions, however, they tend to lose their characteristic shapes and acquire a common spindle-shaped form. This loss of organization emphasizes the close relationship and interdependence of the cells in the body. When they are in the body they support one another and contribute to the health of the whole organism, but when they are removed they lose their characteristic features. The organization of cells in a body is therefore not unlike the organization of a human community, in which the individuals, though capable of independent existence, co-operate for the good of the community—and so for their own benefit.

Like many generalizations, the cell theory was in its original form imperfect and incomplete, but its main contention—'that all living things are composed of cells or the substances derived from them, and that all such cells resemble each other in their structure and origin'—is still valid to-day.

2. PROTOPLASM

The founders of the cell theory attached too much importance to the cell-wall, and described the cell as a hollow cavity bounded by a cell-wall in which the nucleus lay imbedded. This belief was shown to be incorrect by the botanist Hugo von Mohl (1805–72), who pointed out that plant cells contain a grey, jelly-like substance to which he gave the name **protoplasm** (Gk., *protos*, first; *plasma*, form).

Soon after von Mohl's announcement that plant cells contain protoplasm other investigators described a similar substance in the cells of animals; and in 1861 Max Schultze (1825–74), a professor at Bonn, summarized his own observations and those of earlier workers in a statement that "The cells of animals and plants each consist of a mass of protoplasm surrounding a nucleus." Two years later he showed that the protoplasm of animals and plants is essentially the same in its structure and its activities, and so biologists came to recognize that this so-called protoplasm formed the basis of living matter.

Subsequent investigations have shown that this grey, jelly-like material which we call protoplasm is not a single chemical substance, nor even a stable combination of chemical substances,

but that it is constantly undergoing changes in composition as new materials are added to it in the cell, or as materials already in it are changed and perhaps removed from the cell. In fact, the name protoplasm is not an exact term, but it is a convenient name for the substance which we can see in animal and plant cells.

Different parts of protoplasm show affinities for different dyes, so that we may stain the nucleus, for example, without affecting the rest of the protoplasm. In general, the nucleus stains more deeply than the rest of the cell.

3. The Composition of Living Material

As you will see presently, constant chemical changes go on in protoplasm. Nevertheless, the composition of protoplasm remains fairly constant, and so we may calculate the elements present in living material.

According to one authority, the human body consists of the following elements in the given proportions by weight:

Element	Approximate Percentage
Oxygen	65·0
Carbon	18·0
Hydrogen	10·0
Nitrogen	3·0
Calcium	1·5
Phosphorus	1·0
Potassium	0·35
Sulphur	0·25
Sodium	0·15
Chlorine	0·15
Magnesium	0·05
Iron	0·004
Iodine	0·00004
Magnesium, fluorine, and silicon	minute amounts
Aluminium, cobalt, nickel, and copper	traces

These elements are combined together to form a number of different chemical compounds, of which water is by far the most abundant. Chemically, protoplasm is nearly three-fourths water, though the amount varies. We are 65 per cent. water when young, but slightly drier in old age. A jelly-fish is 99·8 per cent. water; a tadpole has almost as great a water content; but a resting seed may be only 8·0 per cent. water.

Most of the remaining chemical substances belong to the group of **organic** chemicals, which are complex chemical substances built on a framework of carbon atoms.

Three main groups of organic chemical compounds are found in living matter:

(1) **Carbohydrates** (L., *carbo*, coal; Gk., *hydor*, water). Relatively simple compounds, built of atoms of carbon, hydrogen, and oxygen (*e.g.*, sugar, starch).

(2) **Fats.** More complex compounds, also built of atoms of carbon, hydrogen, and oxygen. When fats are in a liquid state they are called oils (*e.g.*, meat fat, olive oil).

(3) **Proteins** (Gk., *protos*, first). The most important chemical compounds found in living material, which form an essential constituent of protoplasm and possess larger and more complicated molecules than those of fats or carbohydrates. They are built mainly of atoms of carbon, hydrogen, oxygen, nitrogen, and sulphur.

In addition to water and organic compounds, protoplasm contains some inorganic salts, as, for instance, common salt, which is present in fairly large amounts in our blood. The human body consists approximately of 65 per cent. water, 15 per cent. protein, 14 per cent. fat, 5 per cent. inorganic salts, and 1 per cent. of unidentified material[1].

Some words of caution, however, should be added to our study of the composition of living matter. One must not forget that the composition of living matter is constantly fluctuating as the result of chemical changes that are going on within it. Moreover, one must understand that although scientists may possibly determine what chemical elements are present in living matter, and their proportions, yet it is the **organization,** or arrangement, of these chemicals which makes it possible for life to express itself. There is no doubt that the organization of living matter is the clue to life, and it is not until we have discovered in what way the organic chemicals are organized to form protoplasm that we shall have discovered the mechanism of life.

We speak of living things as living **organisms,** and so emphasize their elaborate organization.

4. Metabolism

Living material is never stable, but is constantly transforming energy and materials. Schwann was aware of this restless activity

[1] Estimate given by Seifriz.

and used the word **metabolism** (Gk., *metabolē*, change) to signify the chemical changes which take place in living organisms.

Before discussing the energy changes in living organisms it is well to decide what we mean by **energy** (Gk., *energeia*, from *en*, in; *ergon*, work), although we may find definition difficult. A physicist considers **energy** as **the capacity of a system to do a job of work.** He uses the term 'work' to describe the overcoming of some opposing force. Some illustrations may make this clear.

When, for instance, a book is pushed along a table energy is required to displace the book by overcoming the force of friction which opposes its movement. A cricketer, as he throws a ball into the air, overcomes the opposing force of gravity, which inclines the ball to rest on the ground. In short, energy is an intangible 'something' which shows its presence by the effect which it produces.

Energy, thus defined, is seen to exist in a number of forms. Heat, electricity, chemical energy, movement, sound, and light are all capable of doing work, and, moreover, they can be transformed one into another. Thus electrical energy will work an electric motor, and so cause movement, and in so doing heat will be produced.

Energy can also be stored so that it is capable of doing work although it may not actually do it for some time. A watch-spring, when wound, stores energy for the movement of the hands. An electric battery contains stored energy, which may be released later as light or warmth. We distinguish, therefore, between **potential energy** (L., *potens*, powerful), which is capable of doing work, and **kinetic energy** (Gk., *kinein*, to move), which is actually doing work.

The most characteristic feature of living material is its power of transforming matter and energy. When the cricketer throws a ball he is transforming potential energy into kinetic energy, and we can show that chemical changes in the muscles accompany this energy change. The cricketer obtained potential energy from his food. Plants, as we shall see presently, transform the kinetic energy in sunlight into potential energy and store this in the formation of chemical substances which may later serve as food for animals or be respired in the plant-tissues to release kinetic energy.

There are, then, constant changes occurring in the composition

of living material, which are related to energy transformations. Those processes which involve the building up of more complicated chemical substances and the storage of potential energy, are included in the term **anabolism** (Gk., *ana*, up; *ballain*, to throw); the word **katabolism** (Gk., *kata*, down) denotes the breaking-down processes whereby energy is released as kinetic energy. Both processes are included in the term metabolism. The metabolic activities of plants are principally anabolic, in contrast to those of animals, which are predominantly katabolic.

SUMMARY

(1) Living things are built of fundamentally similar units called cells.

(2) These cells contain a jelly-like material called protoplasm.

(3) Protoplasm contains a variety of chemical substances organized in some unknown way.

(4) Changes of energy and material included in the term metabolism go on constantly in living material.

SUGGESTIONS FOR HOME STUDY

(1) On what evidence is our knowledge of the composition of living organisms based? Explain the sequence of discoveries which led to our present knowledge.

(2) Define the terms (*a*) protoplasm, (*b*) metabolism, (*c*) a cell.

CHAPTER V

CLASSIFICATION

We ought never to judge of the nature of beings by a single character; for it will always be imperfect and fallacious. Even two or three characters, though extremely general, are often insufficient; it is only by an enumeration of all the characters that a judgment can be formed concerning the permanent and essential qualities of the productions of Nature.

COMTE DE BUFFON, *Natural History*

THERE are very many animals and plants in the world, and they assume a variety of forms. The world population of human beings has been estimated at approximately 1800 millions. The world population of insects could not be estimated with any accuracy, but it would certainly be found to be many thousands of millions of times greater than the human population. As to variety, five hundred thousand different **species** of insects are already known, yet **insects form only one class of animals.**

As man's knowledge of living things widened it became more and more necessary to arrange animals in some methodical fashion to avoid confusion. Many difficulties were overcome, and now we possess a scheme of classification, based on structure, which has persisted with but little change for the past hundred years. In the succeeding pages this system and the stages in its formation are described.

1. LOCAL NAMES

In the Middle Ages the descriptions of animals and plants were generally designed to provide a record of medicinally useful plants or animals. Many of these descriptions had only a local circulation, and the same animal or plant was therefore described under different names in different publications.

Even to-day many wild flowers are known by different popular names in different parts of Britain. The plant which the scientist calls *Arum maculatum* (Fig. 20) is also called lords and ladies, cuckoo-pint, wake-robin, or Jack-in-the-pulpit by the country people of various counties.

Where many varieties of names referred to the same organism great confusion ensued, and so scientists attempted to decide

on one universally accepted name for each known organism. Latin and Greek were the languages of medieval scholarship and so animals and plants bear names which are phrased in these languages and are generally designed to illustrate some feature of the organism to which they refer.

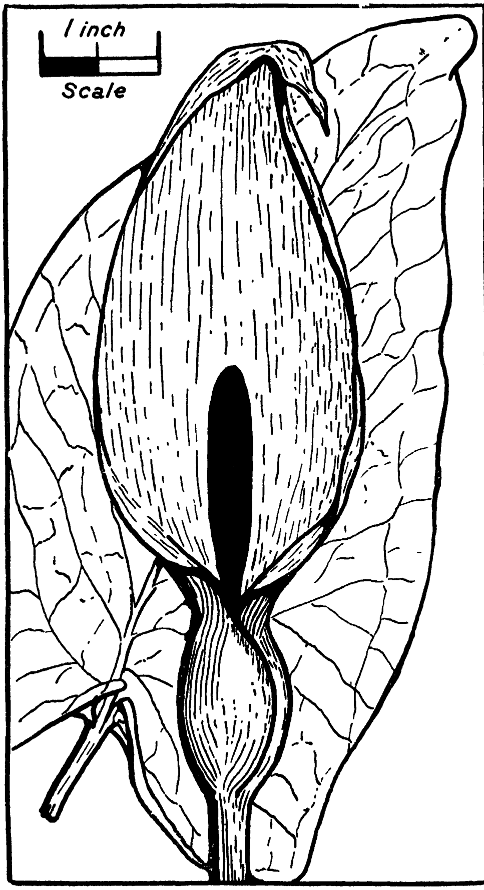

FIG. 20. FLOWER AND LEAF OF ARUM MACULATUM

2. UNITY OF TYPE

As discoveries in the structure of animals and plants were published and assembled by scientists in the sixteenth and seventeenth centuries the resemblances or differences between various organisms became more apparent. Many types were seen to be closely related in their anatomy, while others were very different in their structure. We therefore find that in the later herbals of the sixteenth century plants which closely resembled each other were grouped together into **families,** as, for instance, the Compositæ (the Daisy family), the Leguminosæ (the Pea family), and the Labiatæ (the Dead Nettle family). These families each contained plants which closely resembled one another in their anatomy, especially in the arrangement of their flowers.

Often it was difficult to decide whether a resemblance was an important one or merely a chance or superficial likeness. Many plants, for instance, are of the same colour, but have few other features in common. Mistakes in arrangement were often

made, but in due course many systems for grouping or classifying living organisms according to their likenesses were constructed. All these systems emphasized the surprising unity of structure in living things, and hinted at even greater likenesses in the construction of animals and plants than had previously been believed.

The next stage in classification consisted in the collection of the many groupings of animals and plants, and their inclusion in one comprehensive scheme covering all living things. By the end of the seventeenth century many schemes of classification had been formed. The amalgamation of these schemes was due to the work of the Swedish naturalist Linnæus (Plate 3).

3. Linnæus and Classification

Carl Von Linné, better known to us as Linnæus, was the son of a Swedish pastor. He was born in 1707 and died in 1778. In his youth he spent much of his time collecting animals and plants. He began the study of medicine at the University of Upsala, Sweden, but he finished his studies abroad, chiefly in Holland. He stayed in Holland and elsewhere for three and a half years, and became well known for his excellent work on the classification of plants. At the age of twenty-eight he was granted the degree of Doctor of Medicine at Harderwijk.

On his return to Sweden, Linnæus was appointed a professor at Upsala University. Here he continued to study plants and animals, and developed the system of classification for which he is famous. His greatest work, the *Systema Naturæ*, published in Holland in 1735, provided a comprehensive classification of every known animal and plant, and showed a formal method by which living organisms could be simply described.

Linnæus's scheme of classification has since been greatly modified, but certain features which were retained formed a framework for the later and more elaborate schemes. Linnæus secured the adoption of the so-called **binomial system,** by which each animal or plant is described concisely by two names; one name is generic, and is shared by a group of organisms of which it forms a member, and which resembles it closely; the other is specific to itself and similar forms. Thus, man is called *Homo sapiens*, which is a term including all living men, whether black, yellow, or white. One species of buttercup plant is called *Ranunculus acris*, and is distinguished from *Ranunculus bulbosus*, *Ranunculus*

repens, and the many other forms of buttercup. The name Ranunculus is a generic name, and is shared by the different species of buttercup. The names *acris*, *bulbosus*, and *repens* serve to distinguish the species.

We may perhaps best study the modern scheme of classification by considering first the way in which living things are divided into a number of very different groups called **kingdoms.** Plants and animals are in separate kingdoms, and are distinguished by the striking differences already discussed (p. 39).

Within the animal kingdom a number of large groups called **Phyla** (L., from Gk. *Phylon*, race) are arranged (see table at end of chapter). The members of different phyla are distinguished from one another by fundamental differences of structure. We and the house-fly, for instance, are in different phyla; man, dogs, birds, frogs, and fishes all have backbones, and are included in the phylum Chordata[1] (Gk., *chordē*, string); the house-fly, the lobster, and the spider all have a hard outer skeleton and jointed limbs, and so they are grouped together in the phylum Arthropoda (Gk., *arthron*, joint; *pous*, foot).

The Phyla are in their turn split up into **Classes.** The house-fly and the shrimp, for instance, although they are both in the same phylum, Arthropoda, are placed in different classes. We and many other hairy animals, such as dogs, cows, etc. (all of the phylum Chordata), are placed in the class Mammalia, which bear their young alive and feed them with milk from the breasts (L., *mamma*, breast) and so separated from the birds (class Aves), the frogs (class Amphibia), or the fishes (class Pisces).

Classes are further divided into **Orders,** which are themselves divided into **Families**; these are divided into **Genera,** which finally contain **Species.** In many cases distinct races, or **varieties,** may be recognized within a species; sometimes these groups are sufficiently distinct to be termed sub-species.

To illustrate this arrangement let us as a familiar example take the lions and tigers. These are in different species, known respectively as *Felis leo* and *Felis tigris* (alternative names, *Panthera leo* and *Panthera tigris*), yet both are sufficiently alike in their structure to be included in the genus *Felis*. They belong to the family Felidæ, which, with many other flesh-eating mammals, is included in the order Carnivora.

[1] The phylum Chordata also includes some animals which possess at some time in their lives a rudimentary backbone, or notochord, only.

Ultimately, therefore, the whole scheme of classification is built on the separation of different types of animals and plants into species.

4. The Stability of a Species

The whole scheme of classification must depend on the persistence of the type in a species. If a plant or animal species were to undergo a sudden change, or if the members of two species could often breed together and produce fertile offspring with a blending of the distinctive features of the species, then the system of classification would be so readily upset as to be useless. Members of different species of animals or plants seldom breed together to produce fertile offspring under natural conditions. Matings between some distinct species can be made to occur, as between horses and asses, or donkeys, but the offspring in this case, called mules,[1] are generally sterile and rarely produce offspring. The breeders of tropical fish sometimes mate together members of nearly related species and even of nearly related genera. For example, the Mexican Swordtail (*Xiphophorus helleri*) and the Platy, or Blue Moonfish (*Platypoecilus maculatus*), do not mate together in their natural habitat, but they can be induced to mate together in captivity, and in this case fertile offspring, which combine the features of the parents, are produced.

Interbreeding between the primrose and cowslip flowers is another exception to the rule that two species cannot mate. In this cross fertile offspring are produced, so that you may ask why cowslips and primroses have persisted as distinct species. Since they normally flower at different times and flourish best in different surroundings, they seldom interbreed naturally, and so they preserve their distinctive characters. They are generally referred to as *Primula vulgaris* (the primrose) and *Primula veris* (the cowslip).

However, in spite of the stability of a species, we find considerable **variation** within it (Fig. 21 and Plate 32). If we take the human race as our example we shall find that yellow men, black men, and white men are all very different, though sufficiently alike to be contained in one species. Even within a small community like a school we should find that the boys or girls of the same age would differ greatly in their weight, height, hair-

[1] Mules are produced by the union of a mare and a male ass. The offspring of a stallion and a female ass, which are called hinnys, are rarely bred.

colour, and other features. These differences are mainly hereditary, and are due to the different parentage of the individuals considered, and partly also to differences in upbringing, feeding, health, and other causes.

Yet if we select any one feature and construct a graph in which the variations in that feature are plotted against the numbers of individuals bearing each variation we shall find that

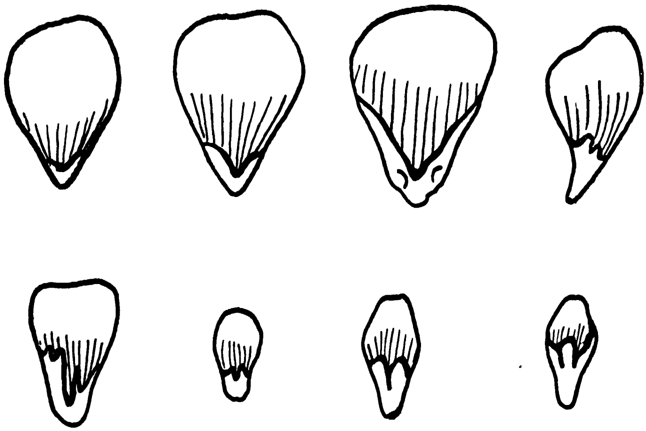

FIG. 21. VARIATION WITHIN A SPECIES

Variations of petals and nectaries of the species *Ranunculus auricomus* are shown. This figure is redrawn after Hermann Muller.

there is an **average** for any character in individuals of the same race, age, and sex. Thus, in the data shown graphically below (Fig. 22), the average height of English girls aged 10 years is 132·1 cm. Yet variations below and in excess of this figure do occur, and so a regular curve can be plotted. This curve, produced by plotting the variations from an average character in a number of individuals, is called a normal frequency curve. It is a typical curve of variation.

If we now compare the normal frequency curves of variation in the height of two geographically separated groups we may find that the position of the apex of the curve—*i.e.*, the average height—differs. For example, the average height of Scotsmen, found in 20 per cent. of the population, lies between 171 cm. and 173 cm., whereas the greatest frequency (28 per cent.) in Sicilians lies between 164 and 168 cm. Small differences of this kind are generally found when groups within a species are separated and rarely interbreed. When interbreeding freely occurs, as has

been happening between the various European emigrants in America during the past hundred years, so-called 'racial' differences tend to grow less.

The term 'race' or 'variety' should be reserved for striking and persistent differences within a species, as, for instance, the differences between Europeans and Negroes. In this case we are justified in maintaining that we are here dealing with two

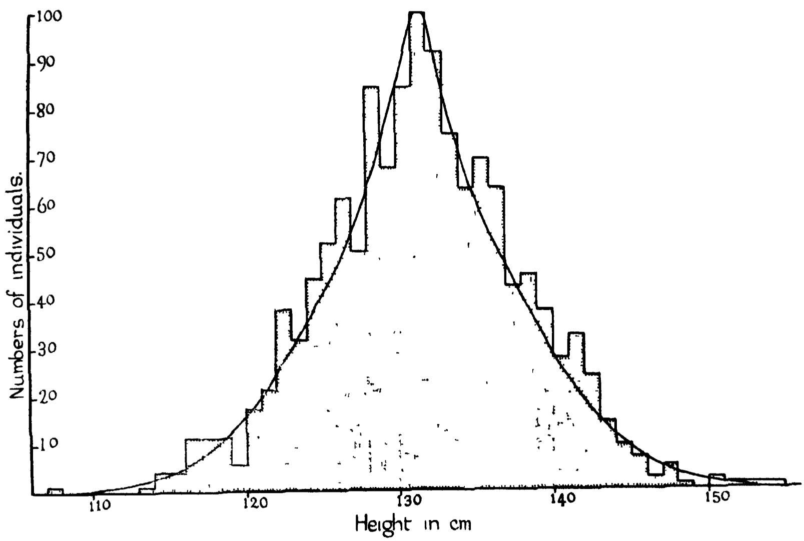

FIG. 22. VARIATION IN HUMAN HEIGHT

The graph shows the heights of 1347 London elementary-school girls aged ten at their last birthdays. The figures are taken from *The Fundamentals of School Health*, by J. Kerr (Allen and Unwin).

distinct races or varieties of the species *Homo sapiens*. In wild animals and plants varieties within a species are generally restricted to a limited geographical distribution.

In conclusion, therefore, it seems clear that:

(1) The many types of animals and plants belong to different species, which retain their distinctive features because they rarely interbreed to produce fertile offspring.

(2) Within a species variations from the normal type do occur.

(3) When groups of individuals within a species are separated and seldom interbreed differences in type may occur. Great geographical separations and very rare

interbreeding may lead to the formation of distinct varieties, or races.

5. Variation in Domestic Animals and Plants

Domestic animals and garden plants show greater variation than their wild counterparts. There are very many different breeds of dogs, cattle, poultry, and goldfish, often very different from one another (Plate 32). These breeds arose in the first place by chance variation from the normal type, and were preserved by breeders, who bred together animals possessing these variations and prevented interbreeding between these breeds and the wild or normal type. In this way bulldogs, terriers, fox-hounds, and other types are maintained as distinct breeds. Nevertheless, they belong to the same species and can breed together and produce fertile offspring. When they do, their offspring, which are called mongrels, lose the distinctive features of their parents.

Horticultural firms which produce special breeds of plants by careful selection must also take care to prevent their breeds from breeding with the normal members of the species. Near-by allotments and gardens are carefully watched lest pollen from the normal plants growing there should fertilize the flowers of the special breeds in the nurseries of the horticulturist.

6. Field-work

It is now time that we left the theoretical consideration of the many diverse forms of life and observed a few living animals and plants. I propose that we should imagine a walk in spring through a meadow to the banks of a stream. It is the end of May, the flowers are appearing, and the animals have emerged from their winter hiding-places to feed and breed.

Plants. Let us first consider the flowers. We notice that many buttercup flowers are opening, and, as we near the river, we find in the marshy ground a flower called a king-cup, or marsh marigold, which resembles a buttercup, but is very much larger and has quite differently shaped leaves. If we consult a flora which describes the classification of plants we shall see that this flower and the buttercups are considered sufficiently similar to be included in the family Ranunculaceæ, yet sufficiently different to be placed in different species and genera. Thus the

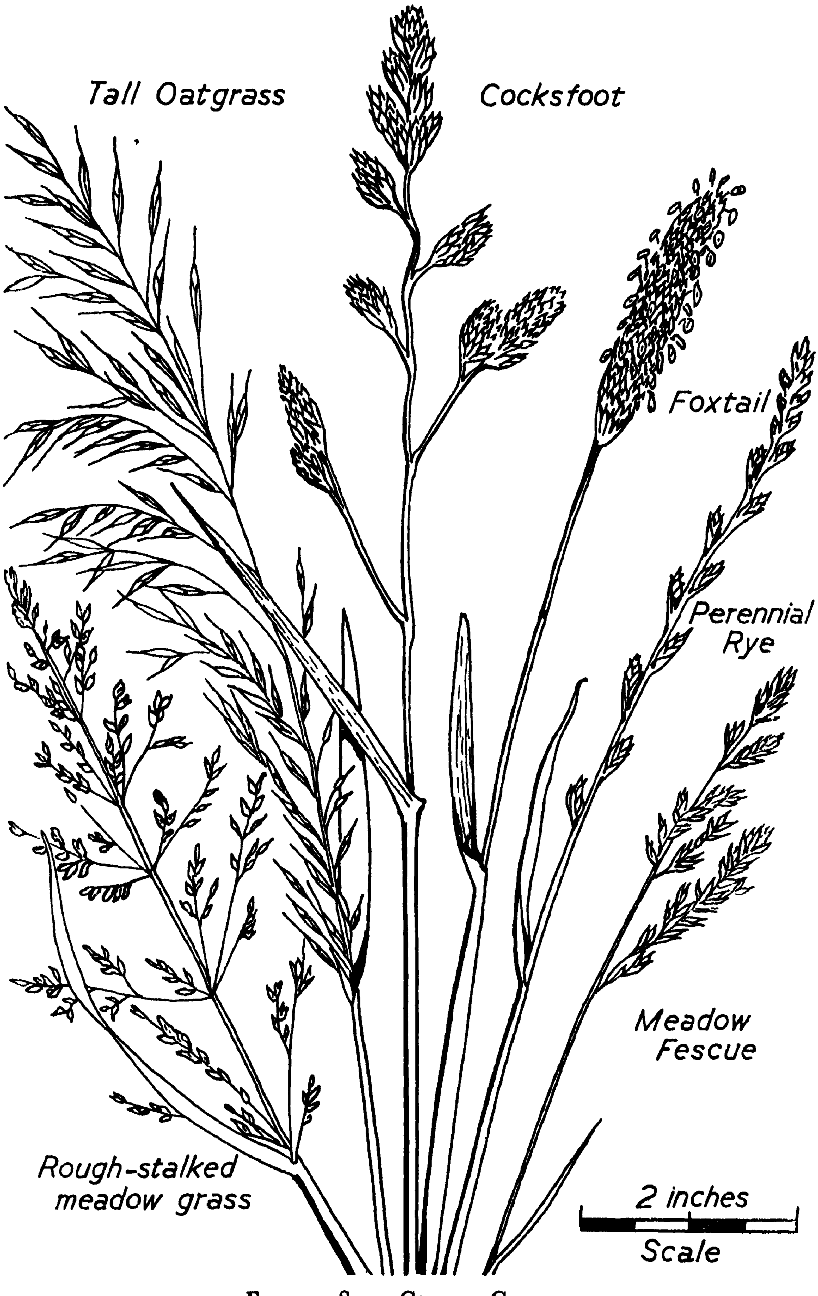

FIG. 23. SOME COMMON GRASSES

Rough-stalked meadow grass, *Poa trivialis*; tall oatgrass, *Arrhenatherum avenaceum*; cocksfoot, *Dactylis glomerata*; meadow foxtail, *Alopecurus pratensis*; perennial rye grass, *Lolium perenne*; meadow fescue, *Festuca pratensis*.

king-cup is called *Caltha palustris*, and the common meadow buttercup is called *Ranunculus acris*.

A further glance at the book of plant classification will show us that there are many species of buttercups—*Ranunculus acris*, *R. bulbosus*, *R. repens*, and others (see p. 37). As we wander through the meadow we may examine the buttercups we find and consider the differences which place these plants in different species, noting at the same time the variations of size and leaf-form within each species.

The grasses belong to another family, the family Gramineæ, the members of which differ greatly from the members of the family Ranunculaceæ. The pollen grains of grasses are not carried by insects, but are borne by the wind from one flower to another. It is interesting to find that the flowers of grasses are green and inconspicuous, and do not attract insects for pollination. A few species of grasses are illustrated for purposes of identification in Fig. 23.

So far we have only considered seed-bearing plants, or members of the phylum Spermatophyta (see table, p. 61). If we can discover a fern on a damp, shady bank we can investigate a member of a different phylum, the Pteridophyta. For the main fern plant does not reproduce by seeds, but by **spores**; these are reproductive cells which are produced in far greater numbers than seeds, and which do not require fertilization by the reproductive cells of another plant. If we discover a fern we may examine the spores, which are to be found in clusters on the lower surfaces of the leaves (Fig. 82).

We may note that the ferns and seed-bearing plants all have bodies which are divided into a root and a shoot. If we can find some mosses in the damper regions of the meadow we shall have examples of yet another phylum of the Plant Kingdom, the Bryophyta, whose members have bodies in which there is little differentiation between root and shoot (Fig. 83).

Animals. At first we shall probably only see flies, bees, and butterflies in the air and small beetles in the grass. As we draw near the stream, however, and especially in the water of the stream, we shall find representatives of many more phyla of the Animal Kingdom.

If we look for vertebrates we shall find fishes in the water, frogs in the damp grass of the river-bank, and a few water-birds on the stream. The moor-hen, a black bird with an orange bill,

is fairly common, and builds its nest on a platform of floating rushes. Another probable sight is the dabchick, a little black bird, which may be recognized by its habit of diving when it hears footsteps, leaving only a number of rippling rings on the surface to mark where it had been. If we tread softly we may see a water-rat sitting on the bank or on a floating branch.

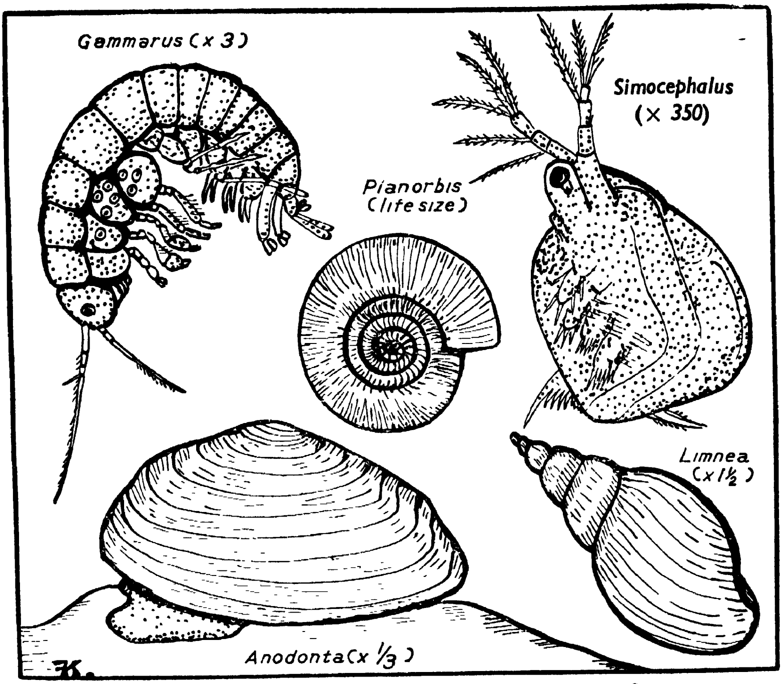

FIG. 24. SOME ANIMALS WHICH LIVE IN PONDS OR IN STREAMS

The rat is an example of a mammal, and so only the reptiles are missing from our survey of vertebrates near the stream. This is understandable, since reptiles generally live in hot, dry places, preferably rocks or sand, where they can bask in the sun. However, if we are lucky we may find a slow-worm, a legless lizard which lives in damp grass.

In the water itself most of the animals belong to the phylum Arthropoda. We may see the Crustaceans Gammarus (the fresh-water shrimp) and Daphnia and Simocephalus (water-fleas), also numbers of larvæ of such Insects as mayflies, dragonflies, and gnats. The phylum Mollusca is represented by the fresh-water snails Planorbis and Limnea and by the fresh-water mussel Anodonta.

The phylum Annelida is represented by leeches and small aquatic worms, especially in or on the mud at the bottom of the stream, and in the soil earthworms everywhere abound.

SUMMARY

(1) The great number and variety of living things are catalogued in logical order.

(2) Each type of organism has one universally accepted name, which generally refers to some feature it possesses.

(3) The degrees of resemblance between organisms are expressed by a scheme of classification, whereby organisms are grouped into varieties (or sub-species), species, genera, families, orders, classes, phyla, and kingdoms. The general adoption of such a scheme was greatly influenced by the work of Linnæus.

(4) A scheme of classification depends on the maintenance of type. Different species seldom breed together under natural conditions and therefore remain distinct, although within a species much variation and even local races or varieties do occur.

(5) The observation of living things is greatly aided by a scheme of classification, for by applying it to some animal or plant strange to us we can rapidly learn much about the organism and the relation which it bears to other types.

SUGGESTIONS FOR HOME STUDY

(1) Describe some of the animals and plants to be found (*a*) by the sea-shore, (*b*) in a park, (*c*) in a wood. As far as possible place the organisms which you mention in their positions in the Plant or Animal Kingdoms.

(2) What do you understand by the term 'species'? Discuss variation within a species.

THE PLANT KINGDOM

Phylum[1]	Distinguishing Features	Examples
Thallophyta .	No separation into root stem and leaves. Mainly aquatic	Seaweeds and some fresh-water weeds
Bryophyta . .	No proper root, sometimes distinct stem and leaves. Gametophyte generation prominent (*see* Chapter XVII)	Mosses and liverworts
Pteridophyta .	Roots which absorb water and salts from the soil. Sporophyte generation prominent	Ferns and club-mosses
Spermatophyta .	Seed-producing plants *Class* 1. Gymnospermæ . . No true flowers, ovules not enclosed in ovaries *Class* 2. Angiospermæ . . True flowers, surrounding ovules contained within carpels	 Pines, firs, etc. Buttercups, oaks, and all other flowering plants

[1] Some authorities prefer to consider the four main Phyla as 'classes' or 'divisions.'

THE ANIMAL KINGDOM

Phylum	Approximate Number of Species[1]	Distinguishing Features	Examples of Animals included
Protozoa	10,000	Body formed of one 'cell' only.	Amœba.[2] Paramecium.[2] Malarial parasite.[2]
Porifera	2500	Body built of many similar cells.	Sponges.
Cœlenterata	7000	Body composed of many and varied cells in two layers enclosing a single digestive cavity.	Sea-anemone.[2] Hydra.[2] Coral. Jelly-fish.
Annelida	4000	(This and later groups have bodies built of many cells formed fundamentally in three layers.) Long segmented bodies without limbs.	Earthworm.[2] Leech. Marine worm.
Platyhelminthes	4500	Flattened bodies without limbs. Simple digestive cavity without anus.	Free-living and parasitic flatworms—*e.g.*, the tape-worm,[2] the liver fluke.[2]
Nematoda	1600	Unsegmented worms with an elongated body pointed at both ends.	Free-living and parasitic threadworms.[2]
Arthropoda	8000	Segmented body with hard outer skeleton. Jointed limbs.	*Class* 1. *Crustacea*. Shrimp.[2] Water-flea.[2] Crab.
	500,000		*Class* 2. *Insecta*. House-fly.[2] Butterfly.[2] Moth.[2] Bee.[2]
	5000		*Class* 3. *Arachnida*. Spider.[2] Scorpion.
Mollusca	61,000	No limbs, moves by creeping foot. Often possesses shell.	Snail. Mussel.[2] Octopus.
Echinodermata	10,000	Radially arranged.	Starfish.[2] Sea-urchin.[2] Sea-lily.[2]

[1] After Neal and Rand.

[2] Forms mentioned in this book.

Phylum Chordata	Approximate Number of Species	Distinguishing Features	Animals included in Phylum
Class Pisces (Fishes)	12,000	Breathe by means of gills and swim in water by means of fins.	Herring[1]. Dogfish. Trout. Cod.
Class Amphibia .	1800	Larval stage aquatic. Adult terrestrial, breathing by means of lungs and through a slimy, smooth skin.	Frog.[1] Toad. Newt. Salamander.
Class Reptilia .	5000	Terrestrial. Breathe by means of lungs. Body covered with scales. Lay eggs.	Lizard. Turtle. Snake. Slow-worm.[1] Extinct Dinosaurs.[1]
Class Aves (Birds) .	20,000	Body covered with feathers. Oviparous.	Sparrow. Thrush. Blackbird. Ostrich. Hen.[1]
Class Mammalia .	7000	Body covered with hair. Bear young alive and nourish them with milk made by mammary glands.	Dog.[1] Cow. Cat. Man.[1]

Groups of Doubtful Affinities

Kingdom of Fungi[2] . . .	Colourless 'plant-like' forms feeding saprophytically or parasitically.	Mucor.[1] Yeast.[1] Potato blight.[1] Mushroom.[1]
Kingdom of Bacteria[2] . . .	Microscopically small organisms. Not cellular.	Lactic Acid Bacteria.[1] Acetic Acid Bacteria.[1] Pathogenic Bacteria.[1]
Kingdom of Viruses . . .	Minute organisms which will pass through finest porcelain filter.	Disease-producing forms.[1]

[1] Forms mentioned in this book. [2] Sometimes included in the Phylum Thallophyta of the Plant Kingdom.

CHAPTER VI

HOW PLANTS FEED

The strong sea-daisies feast on the sun.
A. C. Swinburne, *The Triumph of Time*

Plants, like all other living organisms, need to obtain a supply of materials for growth and repair, together with a supply of energy for movement and other activities. Materials and energy are taken in by plants as they feed.

The absorption of food materials and their conversion for use by an organism are included in the term **nutrition** (L., *nutrix*, nurse). Plant nutrition depends on the soil, the atmosphere, and sunlight.

1. The Material Needs of Plants

Any materials present in plant protoplasm must first have entered the plant as food, and a study of the substances composing the tissues of plants will therefore indicate the materials they absorb.

We may begin by estimating the amount of water which is present in plants. This may be determined by heating the plant at a temperature high enough to drive off water as vapour but not sufficiently high to drive off other substances. The amount of water in plants varies greatly; in leaves the percentage may be between 50 and 90 per cent. by weight; in freshly cut timber it may vary from 38 to 65 per cent.; in seeds it may be 10 per cent. or less.

We may, by heating the remaining material more strongly, drive off the elements carbon (about 45 per cent.), oxygen (about 45 per cent.), hydrogen (about 5 per cent.), and nitrogen (about 1 to 10 per cent.). The fraction which remains after the plant has been strongly heated is called the **ash** and represents about 2 per cent. of the plant. This ash may be chemically tested, and will be found to contain principally the elements potassium, calcium, magnesium, iron, phosphorus, and sulphur, together with traces of many other elements.

There is therefore justification for believing that the ten elements listed above are taken in by plants as food, and we can show

experimentally that this is so by growing plants under such conditions that they can obtain only some of these elements and then observing the results. (Experiment 1, p. 321.)

When young plants are grown with their roots in solutions which are deficient in certain elements characteristic defects will occur in the plant (see Plates 4 and 5). For instance, if nitrogen is absent the seedlings will stop growing and eventually die, thus showing that plants cannot directly use the great volume of nitrogen normally present in air. Lack of magnesium and iron will result in pale-yellow plants, indicating that these elements contribute to the formation of the green colouring-matter in plants. Lack of the other elements will cause stunted growth, because each of these elements plays some definite part in the plant's metabolism.

Scientists have shown by very careful versions of this experiment that, besides the main elements needed by plants, a number of other elements are also needed, although only in minute amounts. Chief among these are boron, zinc, copper, and manganese. Most soils contain amounts of these elements adequate to support plant-growth, but where they are absent the health of plants is affected.

The water-culture experiment described not only shows us that certain elements are necessary for plant-growth, but also that they are absorbed by the roots and therefore that under normal conditions they must be derived from the soil. Moreover, the experiment suggests that the elements are absorbed as simple soluble inorganic salts, like potassium nitrate—a type of nutrition which presents a sharp contrast to the more complex nature of the organic materials taken in by ourselves and by other animals as food (see p. 89).

An exception is provided by the element carbon, which enters the plant otherwise than by the roots. The absorption and use of this element and of the other important elements hydrogen and oxygen is dealt with more fully in the following sections of this chapter.

2. Photosynthesis

A plant left in darkness will become thin, and pale yellow in colour, and an examination of its composition will show that it has absorbed little food material. Light, therefore, seems necessary for plant-growth; it supplies energy.

We now know fairly completely the process whereby plants use the energy in sunlight to build up organic substances in their tissues, and we call it **photosynthesis** (Gk., *phos*, light; *synthesis*, putting together). Its principal features can be shown by experiment (see p. 322). Carbon dioxide, water, and sunlight are absorbed during photosynthesis and form sugars; the gas oxygen is given off during the process.

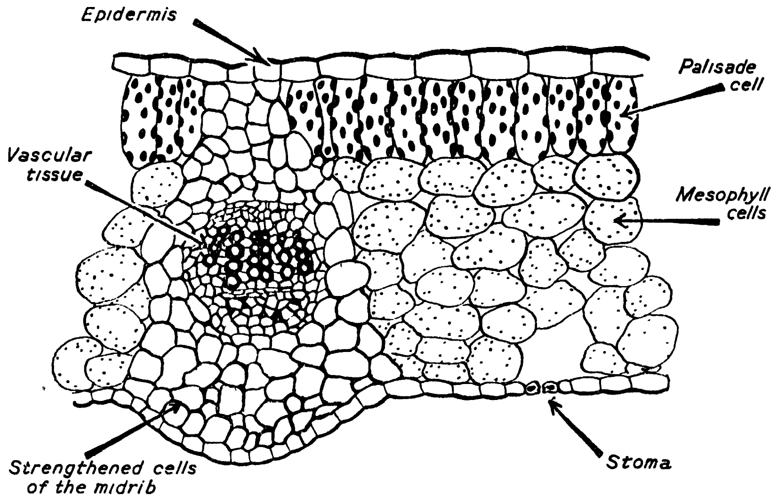

FIG. 25. SECTION OF A FUCHSIA LEAF

The leaf is here seen in transverse section, in diagrammatic form to illustrate the main cell types.

The essential features of this chemical reaction are generally expressed by the chemical equation:

$$6CO_2 + 6H_2O + \text{energy (677 kg. cals.)} = C_6H_{12}O_6 + 6O_2$$

Or we might express this in words: Six molecules of carbon dioxide gas and six molecules of water will, if energy is supplied, combine to form one molecule of sugar and six molecules of oxygen gas. The essential feature is the intake of carbon, which forms a foundation for organic compounds. Photosynthesis is therefore also termed **carbon assimilation.**

In actual fact this reaction is a more complex one, involving a number of stages, but this basic equation shows the important fact that the energy obtained by the absorption of sunlight can be used by plants to build complex carbon compounds from relatively simple inorganic compounds. The sugar formed by

photosynthesis serves as a starting-point for the formation of more complex substances.

The green pigment called **chlorophyll,** which gives plants their colour, plays an essential part in photosynthesis. Its action is complex and is as yet incompletely known, but unless chlorophyll is present in the plant normal feeding cannot take place. If you mount a moss leaf in a drop of water and examine it under a microscope you will see that the chlorophyll is contained in minute granules called **chloroplasts**. Similar granules occur in all the green parts of plants (see Fig. 18).

We may compare photosynthesis to the process whereby water is produced from oxygen and hydrogen in the laboratory. We may mix these two elements without forming water, but if we supply energy, in the form of an electric spark, the gases will combine and water will appear. In the same way a mixture of carbon dioxide and water will not usually form sugar, but in the leaf the energy in sunlight will cause these substances to combine. We can look on the green leaf, then, as a kind of chemical factory, in which carbon compounds are manufactured when the plant is exposed to light. During the process plants change the composition of the air around them by taking carbon dioxide from it and returning oxygen only.

3. Starch Formation

Much of the sugar which has been made by photosynthesis is stored in a suitable form in order that it may be used later to provide a source of energy when the sun is not shining. Most sugars are easily soluble and occupy much space; they are therefore not very suitable substances for storage purposes.

Starch is a carbohydrate more suitable for storage than sugar. Starch molecules, in addition to being insoluble in water, group together to form solid granules, which occupy little space. We therefore find that when the concentration of sugars in a green leaf reaches a certain level much of the sugar becomes converted into starch. Conversely, in darkness, when the concentration of sugars in plants is low, starch becomes converted into sugar.

The molecule of glucose sugar has already been analysed as $C_6H_{12}O_6$; the basic formula for starch is $C_6H_{10}O_5$. We may therefore note that in the conversion of sugar to starch the elements of water (H_2O) are removed from the molecule, and

that in the starch-sugar reaction they are returned. The first type of reaction we call a **condensation,** the second a **hydrolysis** (Gk., *hydro*, water; *lysis*, a dissolving). Both the condensation of sugar to form starch and the hydrolysis of starch to form sugar go on under the influence of several **enzymes,** which are known collectively as **diastase** (Gk., *diastasis*, separation).

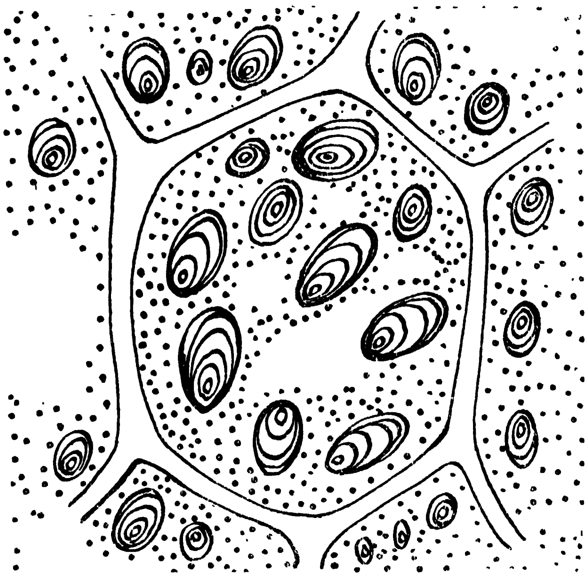

FIG. 26. DIAGRAMMATIC VIEW OF STARCH GRAINS IN THE CELLS OF A POTATO TUBER

Enzymes (Gk., *en*, in; *zymē*, leaven) are chemical substances which promote chemical reactions in living matter.

4. OSMOSIS

Before we can study the way in which water and dissolved chemical substances enter a plant we must take account of a physical phenomenon called **osmosis** (Gk., *osmos*, impulse).

We may demonstrate this process by some simple experiments. First, put a dried grape, prune, or currant in water and notice that it slowly swells up. Next mount the apparatus shown in the accompanying figure (Fig. 27), filling the inverted funnel with golden syrup or some other strong sugar solution. A piece of cellophane or parchment or animal's bladder is tied over the

neck of the funnel. The beaker contains water or a very weak sugar solution. After a short time the level of the solution in the funnel will rise.

In both the above experiments the sugar inside the grape or funnel has pulled water in through the membrane (the wall of the grape, or the parchment, etc.). Whenever a semi-permeable

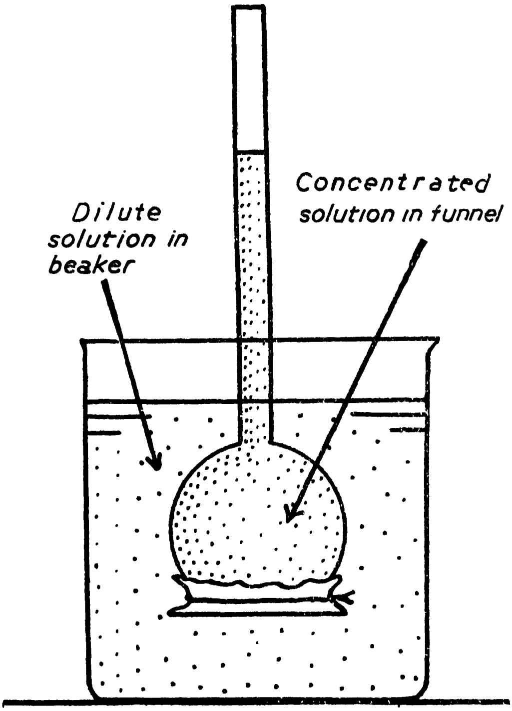

FIG. 27. EXPERIMENT TO ILLUSTRATE OSMOSIS

membrane of this sort separates two such solutions of different concentrations, the solvent of the weaker solution passes into the stronger solution. The pressure which we must apply to the stronger solution to prevent any more of the solvent from entering is called the **osmotic pressure** of the stronger solution.

Protoplasm acts as a membrane, and so the concentrated solution of sugar and other substances in the vacuole of a plant cell draws water into the cell. The outer cell-wall is permeable, and the protoplasm lining it is **selectively permeable**; that is to say, it allows water and certain substances dissolved in it to pass into the central vacuole.

Experiments on osmosis with a living plant cell may be performed on a simple thread-like water-plant called **Spirogyra.** When this plant is placed in a strong solution of sugar the water in the central vacuole will pass out through the protoplasm, which will shrink away from the cell-wall. A cell in which the protoplasm has shrunk in this way is said to have undergone **plasmolysis** (Gk., *plasma*, form; *lysis*, a dissolving), or to be

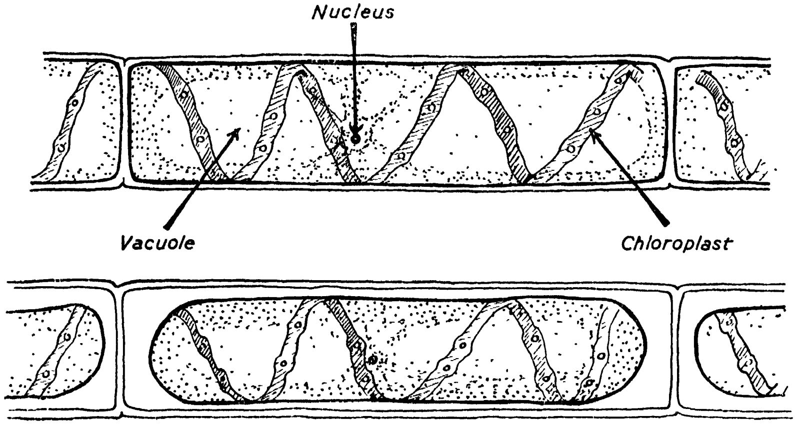

FIG. 28. OSMOSIS IN SPIROGYRA

Above is shown a cell from a filament of Spirogyra, in a state of turgor, under normal conditions; below is the same cell 'plasmolysed' by immersion in a ten-per-cent. solution of sugar.

plasmolysed. The opposite condition, when the protoplasm is pressed tightly against the cell-wall by the pressure of fluid in the cell-vacuole, is called **turgor** (L., *turgēre*, to swell).

5. TRANSPIRATION

Most of the metabolic processes of the plant take place in the leaves. It is therefore not surprising to find that there is a process called **transpiration** (L., *trans*, across; *spirare*, to breathe), by which water and the chemical substances dissolved in it are drawn from the soil and transported to the leaves.

We still do not completely know the mechanism whereby water is raised to such great heights in forest trees, nor, indeed, is our knowledge of all the stages involved in transpiration in small plants complete, but we can recognize the mechanism of certain stages.

When a leaf is examined under a microscope a number of

small pores can be observed, which are found to be especially numerous (as many as 160,000 per square inch in lilac leaves) on the lower surface. Experiments have shown that carbon dioxide and oxygen enter and leave the plant through these pores, and that water evaporates from the leaf through them and from the rest of the leaf surface.

The pores, which are called **stomata** (Gk., *stoma*, mouth),

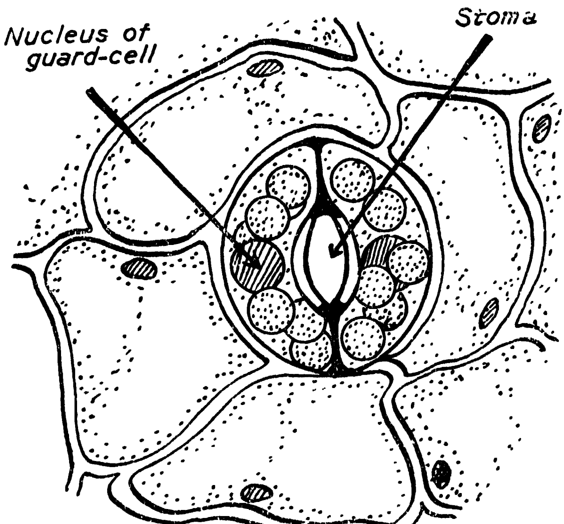

FIG. 29. SURFACE VIEW OF A SINGLE STOMA ON A LEAF, SURROUNDED BY EPIDERMIS CELLS OF THE LEAF SURFACE AND BOUNDED BY TWO GUARD-CELLS

This figure is diagrammatic.

are each controlled by a pair of **guard-cells,** which by their expansion or contraction, can regulate the width of the stoma. These guard-cells contain many chloroplasts. When guard-cells are in a state of turgor they swell up and separate, so widening the pore between them; when they lose too much water they collapse, and by sagging towards one another close the pore. The state of the guard-cells is influenced by many factors. Wind, dry air, and sunlight tend to cause their expansion. If the plant should lose too much water by evaporation the pores are closed and further loss of water is thus prevented.

Under normal conditions water is constantly evaporating from the leaf's surfaces. As the water molecules leave the leaf they tend to draw by attraction those water molecules with

which they are in contact; so water is drawn from the stem into the leaf, where it escapes by evaporation. The experiment shown in Fig. 147 illustrates this process and shows that the evaporation of water from the leaf surfaces draws water through the stem.

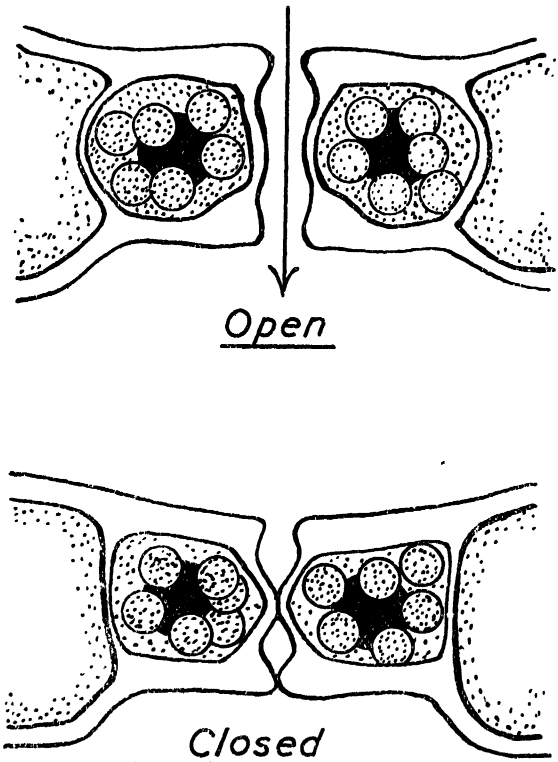

Fig. 30. Single Stoma
Diagrammatic representations of a single stoma viewed in section from one side in the open and the closed position.

When we turn to the root we find that water is forced up the stem by a pressure it exerts. The existence of this **root-pressure** is shown by the water which exudes rapidly from the cut stump of a recently felled tree. Its extent may be shown experimentally (Fig. 31).

Water passes from the soil into the root-hairs by osmosis. As water enters a root-hair and dilutes the fluid in its vacuole the osmotic pressure of the next cell becomes higher than that of the contents of the vacuole in the root-hair, and water therefore

passes through the cortex from one cell to another until it reaches the cell-layer called the **endodermis,** which in some unknown way forces the water into the **xylem** vessels (p. 118) in the centre of the root.

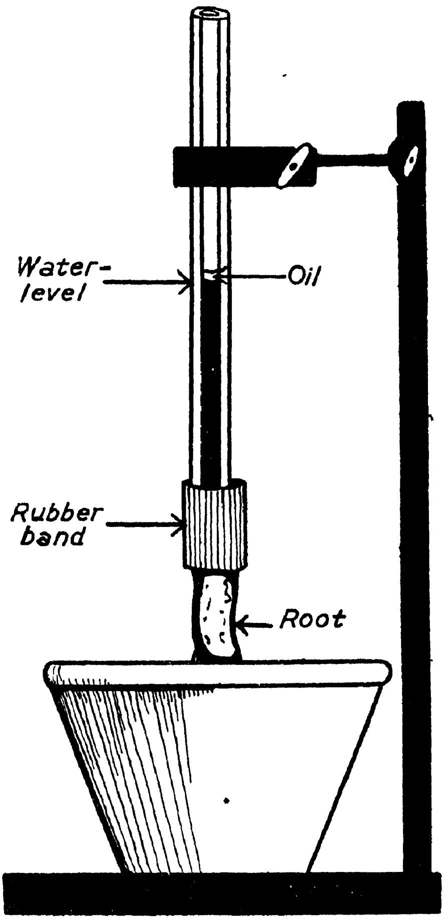

FIG. 31. EXPERIMENT TO DEMONSTRATE ROOT-PRESSURE
Water, exuded from the freshly cut root, will be seen to rise slowly up the glass tube.

Water is therefore drawn up the stem by forces in the leaves, after having been pushed up into it by forces in the root;[1] water and dissolved salts thus travelling in these two stages from the soil to the leaves.

[1] It has been suggested that other forces in the stem, including capillary action, may also play a part in transpiration.

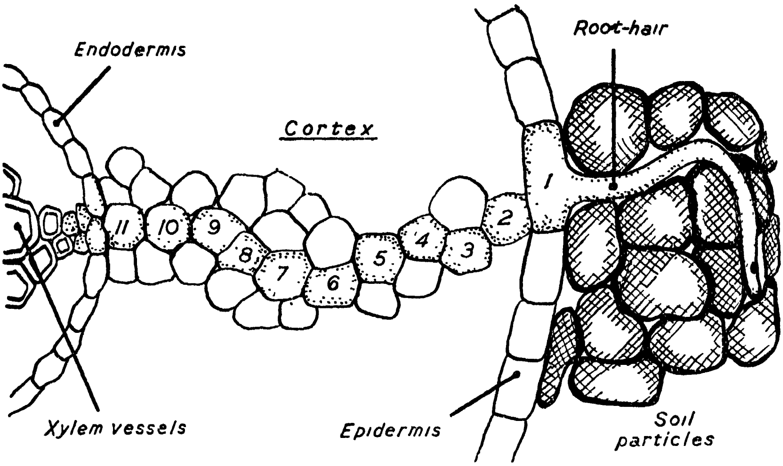

FIG. 32. DIAGRAM OF A SMALL PORTION OF A ROOT
The root is shown in cross-section in order to illustrate the passage of water from a root-hair to the conducting Xylem vessels in the centre of the root.

SUMMARY

(1) Plants, like ourselves, feed in order to obtain a supply of material and energy.

(2) Materials for plant growth are obtained by the plant from the soil and the air.

(3) Plants obtain energy from sunlight by means of the green pigment chlorophyll, which enables a chemical reaction called photosynthesis to occur, by which energy is stored by the plant, largely in the form of carbohydrates.

(4) The sugars manufactured during photosynthesis are mainly converted into an insoluble compound called starch, and are stored in that form by the plant.

5. A constant stream of water and dissolved chemical substances, called the transpiration stream, passes through the plant, and by this means materials are carried from the soil to the leaves, where photosynthesis occurs. Excess water escapes from the plant over the surfaces of the leaves.

SUGGESTIONS FOR HOME STUDY

(1) Explain how a plant obtains the materials it needs for growth and repair.

(2) Why is sunlight essential to plant growth?

CHAPTER VII

THE SOIL AND PLANT GROWTH

> The thirsty Earth soaks up the rain,
> And drinks, and gapes for Drink again;
> The Plants suck in the Earth, and are
> With constant Drinking fresh and fair.
>
> A. COWLEY, *Drinking*

PLANTS, as we have seen, derive a great deal of their food from the soil. Plant growth must therefore depend on the substances present in the soil, and whether they are in such a form that the plant can absorb them.

1. THE CONTENT OF SOIL

The aggregation of particles which we call soil varies greatly in different parts of the country, and influences in an important way the plants which grow in it. Certain soils will support the life of many plants, while others will favour the growth of certain species only and some are unsuitable for plant growth.

Despite their variations in colour, texture, and content, soils have five main features in common: they contain (i) mineral particles, (ii) the decaying remains of plants and animals, (iii) carbon dioxide and oxygen, (iv) water, and (v) microscopically small living organisms in very great numbers. Variations in soil structure depend on the nature and the amounts of these constituents.

The mineral particles are derived from the fragmentation of rocks as the result of frost, wind, and rain. Particles of relatively large size we term **sand,** while minute particles form what we know as **clay.** These latter particles have become chemically and physically altered by the action of the weather, and supply much of a plant's food.

Mixed with the sand and clay particles we find the decaying remains of animals and plants, which form what we call **humus** (L., *humus*, earth). This constituent of soil provides food-material for plants and has a great capacity for holding moisture.

Between the soil particles we find air-spaces, and in a damp soil we find round each particle a thin film of water.

Finally, the soil teems with living things, including insects, worms, protozoa, and bacteria. These organisms perform valuable chemical and physical activities in the soil, and so promote healthy plant growth in a manner which we shall consider shortly.

Before passing on to a more detailed description of soil structure, we can easily make an approximate analysis of any soil with the aid of a gas-cylinder jar and some water. A sample of soil is placed in the jar with some water, and the whole is shaken vigorously and is then allowed to settle. The heavy sand particles will first settle, followed by the clay particles, while the humus will float on the water, as shown in Fig. 33.

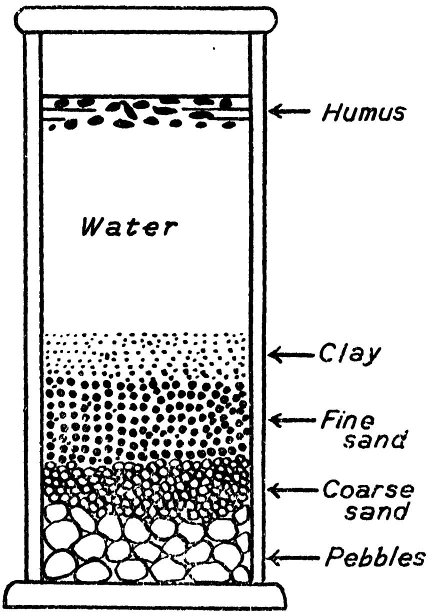

FIG. 33. EXPERIMENT TO SHOW THE PHYSICAL COMPOSITION OF SOIL

2. THE SOIL AND PLANT GROWTH

Since we have surveyed the nature of soil we may inquire how variations in its composition can affect plant growth.

A plant derives inorganic salts and water from the soil through its roots, and the latter also breathe, taking in oxygen and giving off carbon dioxide. Hence a suitable soil for plant growth will be one that will favour these requirements.

The water and air content of soil is influenced by the size of the soil particles. Large soil particles have large air-spaces between them, while small clay particles are more tightly packed. Thus a sandy soil will be better aerated than a clayey soil.

The large air-spaces in sandy soil will, however, permit but little retention of water, which will drain freely through them. After rain, therefore, a sandy soil will contain air but little water, while clay will be waterlogged but will have little or no air. Yet this water in the clay soil can only be drawn up with difficulty

by the plant, owing to the attraction of the water to the small particles and the fine channels between them, which provides resistance to water movement.

Clearly, therefore, the two extremes of sand and clay are both unsuitable for plant growth, since the former contains air but little water while the latter contains water but little air. A compromise soil called a **loam,** which contains balanced amounts of clay and sand particles, is needed for the healthy growth of plants. Most garden soils are sandy or clayey loams.

Humus imparts to the soil two conditions valuable for plant growth. First, it provides food material for the plant, since it decomposes to form inorganic salts; secondly, it loosens the texture of the soil, thus allowing the roots to breathe freely, and, thirdly, it retains moisture. Hence we can to some extent remedy the faults of sand or clay by the addition of humus in the form of manure. Yet we must be careful to avoid excess of humus, since the effect of large amounts of organic matter might be to make the soil too acid, acid substances being produced freely in the early stages of decay.

The population of living organisms in the soil influences the growth of plants principally by means of the chemical changes which the bacteria promote in the soil and by the movements of soil which the worms initiate. Both these activities will be considered later in greater detail. The nature of the population of living things is directly influenced in its turn by the soil's composition, since, like the plants which grow in the soil, the organisms it comprises depend on an adequate supply of water, oxygen, and mineral salts, and are sensitive to great extremes of alkalinity or acidity.

Under natural conditions the features of a soil can often be recognized by observing the plants which grow in it. Thus an acid soil is revealed by the presence of creeping sorrel and spurrey; we can grow *Primula auricula* and *Anemone alpina* on chalky soils, but not their relatives *Primula viscosa* and *Anemone sulphurea*; rhododendrons flourish in acid soils but dislike lime, and so on.

Most gardeners are unwilling to tolerate unbalanced soils but attempt to correct deficiencies or to compensate for any excess. They will add lime to a clay soil to make it less acid and at the same time more porous, because the lime causes the fine clay particles to **flocculate** (L., *floccus*, flock of wool)—*i.e.*, to stick together in clumps. The addition of manure or leaf mould

to a sandy soil will increase its content of food supplies and also help it to retain water.

3. Micro-organisms in the Soil

When we dig a garden we find a number of small animals, such as worms, beetles, ants, centipedes, and others. But besides these there are some other living things which are too small to

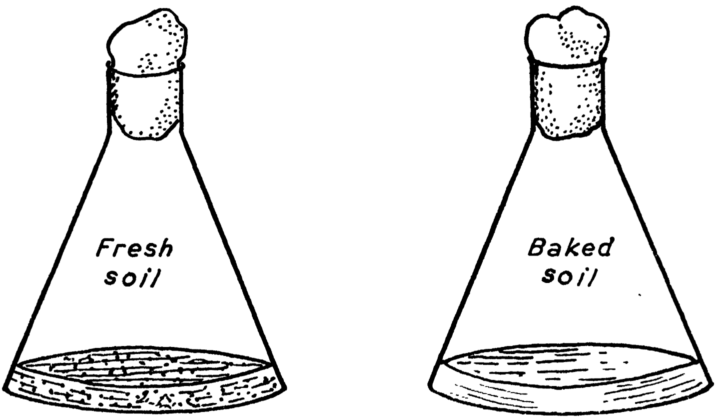

Fig. 34. Experiment to show the Presence of Micro-organisms in Soil

be seen unless we use a microscope, though we can show their presence by some simple experiments.

If we take some fresh garden soil and bake it in an oven we shall kill any living things in it. We then take two flasks, each containing a little milk and closed with cotton-wool stoppers. The flasks are heated until the milk boils gently for a few minutes, so that any forms of life in the milk are destroyed (see p. 213). A little baked soil is placed in one flask, some fresh soil in the other, and the cotton-wool stoppers replaced; we leave both flasks in a warm place until the next day. When we then examine them we find that the flask containing baked soil smells fresh and the milk seems unchanged, while the flask containing milk and unbaked soil smells like cheese and the milk is seen to be sour. Therefore there must be something present in soil which is destroyed by heating and which can cause milk to become sour. We can look for this 'something' by examining a few drops of milk from each flask under a powerful microscope.

In each case we shall see the round, fat droplets of milk but

in the sour milk we shall also find many minute rod-shaped creatures called **bacteria** (Chapter XX), which are very important in soil as they cause many chemical reactions to occur.

Many of these bacteria breathe in a manner comparable to our own. This may be shown by another simple experiment. The apparatus shown below is assembled, and a bag of fresh garden soil is suspended in one flask. The level of the liquid in

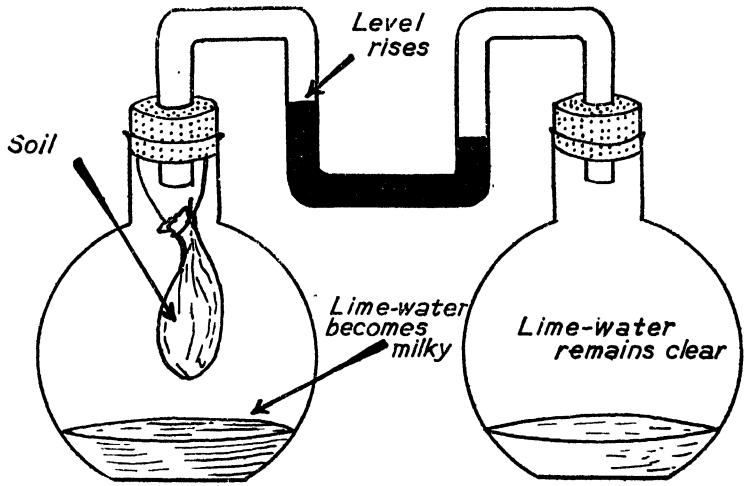

FIG. 35. EXPERIMENT TO SHOW THAT THE MICRO-ORGANISMS IN SOIL BREATHE AND GIVE OFF CARBON DIOXIDE

the U-shaped tube is marked by stamp-paper. After two days we should find that the water in the U-tube has moved towards the soil flask, showing that some of the air has been used by the living things in the soil. The lime-water in the soil flask has turned milky, indicating that carbon dioxide has been produced. (Compare with experiments on pp. 19 and 111.)

However, we are more concerned here with the feeding habits of these bacteria, for it is by their method of feeding that these micro-organisms cause chemical reactions to occur in the soil.

Broadly speaking, we may distinguish four main groups of soil bacteria. (i) Some feed on the decaying bodies of animals and plants and convert some of the complex substances, called proteins, in them to simpler compounds like ammonia. (ii) Others feed on the free nitrogen in the air and build it into proteins in their own bodies. (iii) Another group continue the work of the first group and convert ammonium salts to soluble

nitrates, which can be used by the plant. (iv) The fourth group undo the work of group three, and convert soluble nitrates to ammonia. Together, therefore, these bacteria carry out a series of interrelated chemical reactions, which are primarily concerned with the chemical element called nitrogen. This element is very important for plant growth and, therefore, a study of the soil bacteria is essential for a proper understanding of the management of crop plants.

NITROGEN-TRANSFORMING BACTERIA

NAME	ACTIVITY	CHEMICAL CHANGE INVOLVED
1. *Bacterium mycoides*, etc.	Cause decay	Proteins → ammonia, etc.
2. *Bacillus radicicola* (on roots of clover, etc.) *Clostridium*, *Azotobacter* } In soil	Fix atmospheric nitrogen	Nitrogen → proteins
3. *Nitrosomonas*, *Nitrobacter*	Nitrification	Ammonium salts → nitrites Nitrites → nitrates
4. *Bacterium mycoides*, etc.	Denitrification	Nitrates → nitrites → ammonia[1]

4. EARTHWORMS AND THE SOIL

Though earthworms are insignificant in size, they are known to play an essential part in the levelling of mountains, the burying of ancient monuments, and in the maintenance of fertile soil suitable for plant growth. The great naturalist, Charles Darwin, published a book called *The Formation of Vegetable Mould through the Action of Worms*, in which he put forward these conclusions, which he supported by a considerable weight of evidence, some of which we may consider here.

Earthworms have poor senses, for they cannot see, beyond being able to distinguish between light and darkness; they are unable to hear, and can barely smell; only their sense of touch is well developed. Yet they build elaborate burrows, which are often lined with leaves and have the entrance closed by a leaf or other object. As the earthworm tunnels it eats its way through the earth, much of which passes through the body of the worm and is ejected as a 'worm-cast' on the surface of the soil.

Worms do not penetrate to a great depth, seldom venturing

[1] *B. mycoides* behaves in this way when free oxygen is scarce and there is a good supply of easily oxidized organic material—*e.g.*, in very rich or waterlogged land.

beyond a depth of four feet, and it is therefore mainly the upper layers of earth that are disturbed by their activities. As many as 53,767 worms may live in these upper layers in an acre of rich garden soil. The soil of a cornfield may contain about half this number. Clearly, therefore, the movement of soil through the bodies of earthworms in a garden or field must be very considerable. It has been estimated that at least ten tons of soil must pass annually through the bodies of the earthworms inhabiting one acre of average soil.

This redistribution of earth particularly affects the vegetable mould in the surface layers. Since worms digest half-decayed leaves they help in the production of the humus acids which aid in the decomposition of rocks. The constant movement of soil brings decaying matter to the surface, where its decomposition is hastened, and it also helps to grind more finely the particles of soil or organic matter. In short, the worms by their activities prepare the soil in the best possible way for the growth of plants. Like the most careful gardener, they mix organic matter with the soil particles, make air-spaces, and bring about excellent drainage of the soil.

The influence of earthworms on the levelling of land surfaces is surprisingly great. The fine castings which they produce are apt to roll down any sloping surface, and this action is greatly facilitated by the action of wind or rain. If even a small fraction of the layer of fine earth, ·2 of an inch in thickness, which is yearly brought to the surface by worms, is carried away by wind and rain, great changes in the land surface will be produced in a few million years, a period of time which no geologist considers very long.

As a footnote to Darwin's observations on the influence of earthworms we may consider their effect on the fortunes of an amateur gardener. In 1906 a certain Dr George Sheffield Oliver, of Texas, U.S.A., read Darwin's book and decided that he would experiment on the influence of earthworms on his garden soil. He therefore took a number of pots of earth and placed worms in some of them, first making sure, however, that the soil in the other pots contained neither worms nor their eggs. Plants of one species were then planted in all the pots.

The results which Dr Oliver obtained were so strikingly in favour of that soil containing the earthworms that he decided to investigate the problem more fully on a commercial scale.

He obtained many varieties of worms and bred them on a large scale, feeding them on soapy water and carob pods in order to give them adequate amounts of fats and proteins. These worms he sold to farmers and gardeners who wished to increase the fertility of their soils. Many soils had lost their fertility as the result of being treated with strong chemical fertilizers, which had killed the worm population, and these soils responded well to the treatment advised by Dr Oliver, namely, the restocking of the land with worms. By mating different varieties of worms Dr Oliver produced worms suitable for different climates and various soils. His most successful species were obtained by crossing a small English Brandling worm and a Californian Orchard worm. The offspring of this cross are very hardy and have prodigious energy. Dr Oliver's business has by now earned him a small fortune and further emphasized the part which worms play in the fertility of the soil.

5. Crop Rotation

During the past seventy years British farmers have been in constant competition with overseas agriculturists. Wheat, cheese, butter, and meat can be produced in greater quantities and more economically in the colonies and elsewhere than in Britain. The general scope of British agriculture has therefore altered, concentrating first on meat, later on dairying, and more recently on eggs and vegetables. Fortunately, the consumption of protective foods, such as milk and butter, has increased in more recent years,[1] and owing to difficulties of transport, these foods are not imported in such quantities as are cereals and frozen meat.

Yet, in spite of the general trend away from cereal crops, government subsidies and restrictions on imports reduced the amounts of cereal and meat imports during the nineteen thirties and made mixed crop farming more profitable once again.

The basis of mixed crop farming is the principle that no one plant crop should be planted for too many successive years on the same soil. Since different crops remove different proportions of chemical substances from the soil, it is possible to keep the balance of the latter constant by changing the crop yearly. This principle of rotation of crops was known to the old Romans,

[1] See p. 97.

and has evolved progressively since then. Some four-course rotations are shown below.

THE ROTATION OF CROPS

—	1	2	3
1st year	Turnips (*a*)	Potatoes (*a*)	Potatoes (*a*)
2nd year	Wheat (*b*)	Mustard or wheat (*b*)	Sugar-beet (*a*)
3rd year	Clover (*c*)	Wheat or oats (*b*)	Wheat (*b*)
4th year	Wheat (*b*)	Clover or peas (*c*)	Clover (*c*)

In all cases the rotation is in the order root crops (*a*), corn or other cereals (*b*), and clover or other legumes (*c*). Sometimes

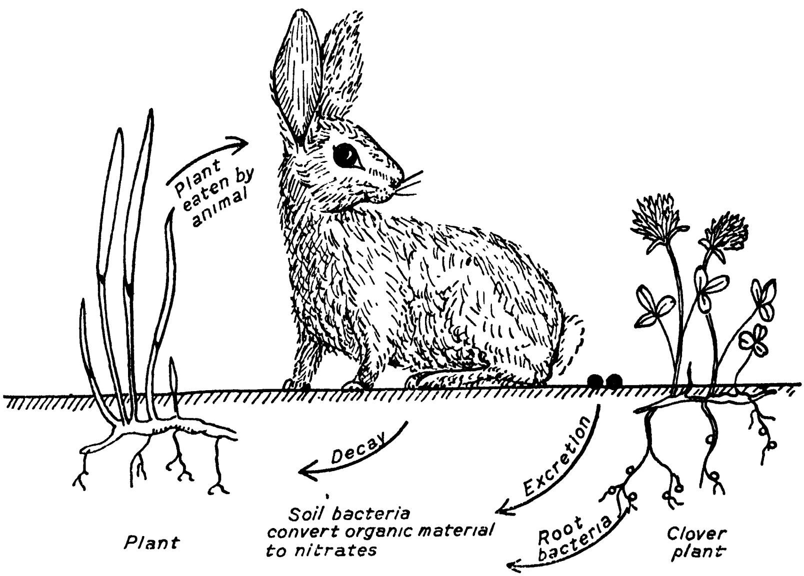

FIG. 36. SIMPLIFIED DIAGRAM OF THE NITROGEN CYCLE

Plants are eaten by animals, the excretions of animals and their dead bodies are converted by soil bacteria into soluble nitrates, which plants can absorb, and the bacteria in the root nodules of clover plants (see Plate 6), and other bacteria in the soil, fix the nitrogen in the atmosphere.

the land is allowed to stand **fallow**—*i.e.*, without crops for a year—and sometimes artificial fertilizers are employed.

Nitrogen is an important constituent of plants; mixed farming and crop rotation aim especially at maintaining the nitrogen content of the soil constant.

Nitrogen is removed from the soil by (1) plants, (2) denitrifying

bacteria. It returns to the soil by (*a*) the excretion of animals, (*b*) the decay of animal and plant bodies, (*c*) the activities of certain bacteria, some of which live on the roots of clover, peas, and other legumes, (*d*) a little may come down in the rain during thunderstorms.

Farmers also repair deficiencies of nitrogen, phosphorus, and other elements by applying to the soil chemical compounds containing these elements. Ammonium sulphate, sodium nitrate, and potassium nitrate are three such chemical fertilizers which are commonly used.

A mixed farm is therefore to a certain extent self-sufficient. Some plant crops, such as wheat, remove nitrates and ammonium compounds from the soil; others, such as clover, by the action of their root bacteria return nitrogen to the soil. Cows and other crop animals feed on grass and other home-produced foodstuffs, and their excretions form **manure,** which returns certain nitrates and ammonium compounds to the soil. Any soil deficiencies which cannot be corrected by natural means can be remedied by chemical fertilizers.

There is not space to do more than to suggest here some of the factors which may influence the nature of a farm. Soil balance and the fluctuating prices of farm crops make the whole subject an intricate one, which must alter with world conditions, advances in farm implements, and discoveries in soil and plant science.

SUMMARY

(1) Plants obtain much of their food from the soil.

(2) Soil contains mineral particles, decaying organic matter, air, water, and living things. Each of these influences the fertility of the soil.

(3) Nitrogen and other chemical substances are removed from the soil by some living things and returned to it by others.

(4) By careful rotation of crops and the use of fertilizers farmers preserve the fertility of soils.

SUGGESTIONS FOR HOME STUDY

(1) If you wish to grow plants in a window-box what factors must you consider?

(2) Discuss the relation between agriculture and the soil.

CHAPTER VIII

THE FOOD OF ANIMALS

A little meat best fits a little belly.
R. HERRICK, *A Ternary of Littles*

EATING is a familiar activity, yet how few of us have paused to consider why it is that, in spite of the great weight of food and water we consume, our total weight varies so little from day to day. A ten-stone man may eat 3·3 kilograms of food daily, yet his total weight may remain almost constant. What happens, then, to the great bulk of food which he eats?

1. THE DESTINATION OF FOOD

An early attempt to discover the fate of the food which we eat was made by an Italian, Sanctorius (1561–1636), who constructed a balance on which he could sit, eat, and sleep over long periods. He found that after eating he gradually lost the weight which he had gained by the intake of food, and he ascribed this to 'insensible perspiration.'

In this explanation he was partly correct, because we constantly lose water by evaporation from the surfaces of the lungs and the skin (p. 329). Besides this we are losing the carbon dioxide we breathe out (p. 18). Finally, we excrete solids and water (p. 142).

It is possible to construct a balance-sheet to show the weight of food consumed by a man and the ways in which he loses a weight nearly equivalent to the food, water, and oxygen which have entered his body. Such a day's balance sheet for a resting man weighing ten stone is given below.

WEIGHT GAINED (IN KG.)		WEIGHT LOST (IN KG.)	
Food	1·1	Excreted solids	0·07
Drink	1·5	Excreted water	1·3
Oxygen	0·7	Evaporated water	1·1
		Carbon dioxide	0·82
Total	3·3	*Total*	3·29

Ten grammes are not accounted for, but if we were to weigh our man we should find that he has gained in weight by ten grammes. We find, in fact, that all the food which entered the body during our experiment can be traced. This is in accordance with the **Law of Conservation of Matter,** which states that matter cannot be created or destroyed.

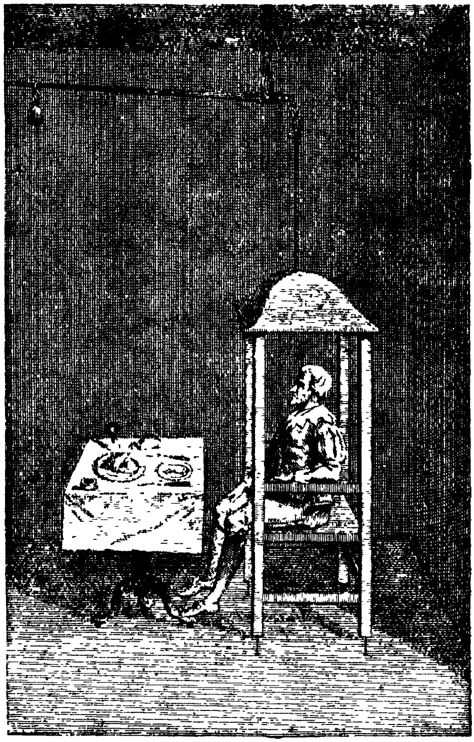

FIG. 37. SANCTORIUS SEATED ON HIS BALANCE
From *A Short History of Medicine*, by Charles Singer (Oxford University Press)

Yet our experiment has so far told us little about the fate of our food, since we clearly do not absorb food merely in order that it may be excreted. We must look for some relationship between the food which we eat and the activity of our bodies.

2. THE ENERGY IN FOOD

If an animal is placed in a box which neither gains nor loses heat with respect to the surrounding atmosphere any movements

which it may make are accompanied by heat which may be measured. Such a heat-proof box is called a **calorimeter.** When such an experiment is performed it is found that the amount of energy given off as heat by the animal is directly related to the amount of oxygen which the animal has breathed in and the amount of carbon dioxide which it has breathed out. It is

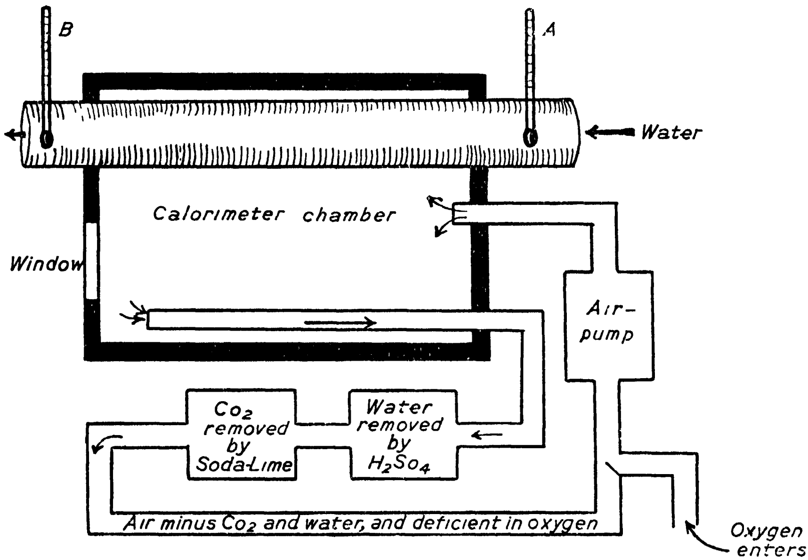

FIG. 38. DIAGRAM TO SHOW THE PRINCIPLE OF THE ATWATER BENEDICT RESPIRATION CALORIMETER

The differences in temperatures between the water passing the thermometers *A* and *B* gives some measure of the heat output of an animal in the calorimeter chamber. The oxygen intake, and the carbon dioxide and water output can also be measured. This diagram is redrawn after Halliburton.

also found that the amount of energy given off is in relation to the amount of food which has been or is shortly to be consumed by the animal, and that the amount of heat generated is almost equivalent to the amount of heat which would be generated if the animal's food were burnt in another calorimeter. Energy is therefore neither created nor destroyed, and so the **Law of the Conservation of Energy** is adhered to.

For example, a ten-stone man may consume enough food daily to yield 2400 kg. calories (one kg. calorie is the amount of heat needed to raise the temperature of one thousand grammes of water by one degree centigrade). If a ten-stone man is placed in a calorimeter during the period in which he would have consumed sufficient food to yield 2400 kg. calories the amount of heat lost

by his body would, it has been calculated, be 2190 kg. calories. 210 kg. calories are not accounted for in this experiment, partly due to the incomplete use of the food by the man and partly to the storage of food (which can be observed by recording the weight of the man).

It is clear that food has an energy value which may be measured in terms of the units of heat energy, or calories, which would be given off if the food were burnt. It is therefore possible to assess the energy-value of foods experimentally in this way, and a few examples are given below:

Food	Kilogramme Calories per Pound
Cabbage	190
Milk	303 (376 per pint)
Fowl	598
Kippers	974
Brown bread	1155
White bread	1182
Sirloin of beef	1726
Cheese	1862
Chocolate	2515
Butter	3497
Cod-liver oil	4213

The food requirements of human beings vary according to the amount of work which each human being does during the day. A sedentary clerk or other brain-worker will require very much less food than a wood-cutter. A list of a few professions with their calculated daily energy requirements is given below:

Profession	Kilogramme Calories
Monk	2304
Teacher	2600
Housewife or typist	2800
Soldier in war	3146
Farm-labourer	4100
Woodcutter	5500
College football player (American estimate)	5742

3. The Materials in Food

House-flies, butterflies, and many other insects are almost fully grown when they emerge from the pupal case. Their food, therefore, which consists almost entirely of sugar and water, provides them with energy only.

We, however, need certain chemical substances to build the protoplasm in our bodies. We especially require the elements

carbon, nitrogen, hydrogen, and oxygen, which we take in our food in the form of proteins, carbohydrates, and fats (see p. 46). We may summarize the utility of these elements as follows:

(*a*) **Proteins.** Used to replace old tissues or to provide new tissue; they may also be 'burnt' as fuel, one gramme yielding 4·1 calories.

(*b*) **Carbohydrates.** Either 'burnt' immediately to release energy or stored as glycogen. One gramme yields 4·1 calories.

(*c*) **Fats.** Either burnt immediately to release energy or stored to provide a source of potential energy and used to provide cushioning material to protect internal organs. One gramme of fat yields 9·3 calories.

A number of other elements help to build the human body. Three of these substances are especially important; they are required in fairly large amounts, and if we do not obtain our requirements our health will suffer.

(1) **Calcium.** Needed for the healthy formation of bones and teeth, the activity of muscle and nerve, and for the clotting of blood. Adults require two-fifths to one gramme of calcium per day; children need one gramme per day.

(2) **Phosphorus.** Phosphorus and calcium act together in the formation of bones and teeth. Neither element can be effective without the other. Adults require 1·3 grammes per day; children need two grammes per day.

(3) **Iron.** Iron forms part of a chemical substance called **hæmoglobin,** which colours our blood red. When our food does not contain enough iron we become pale-lipped and tired, and are said to suffer from **anæmia.** Girls need more iron than boys. Men require 0·012 grammes of iron daily. Women need 0·015 grammes per day. A child can keep healthy with a daily intake of 0·001 grammes.

Calcium and phosphorus are abundant in milk, cheese, egg-yolk, and almonds. Iron is present in egg-yolk, meat, spinach, water-cress, dried beans and peas, dried prunes, and some other foodstuffs.

4. Vitamins

Our survey of the substances present in animals' foods is not yet complete, since a diet of refined proteins, fats, carbohydrates, and mineral salts, though providing the energy and the apparent materials needed by the body, does not support life.

In 1888 a Swiss worker, Dr Lunin, fed some mice on such a diet, but to his surprise the animals rapidly sickened and died. Soon afterwards a Dutch worker repeated the experiment, but added a trace of fresh milk to the diet. His animals did not die, thus showing that milk must contain some substances other than the 3·4 per cent. protein, 4·8 per cent. carbohydrate, 3·5 per cent. fat, and the phosphorus, calcium, and water of which it was then known to consist.

In 1912 Sir Frederick Gowland Hopkins showed by experiments that fresh foods contain very small amounts of certain chemical substances which must be present in the diet of a healthy animal. These chemical substances are called **accessory food factors,** or, more shortly, **vitamins.** Later research has shown that many distinct vitamins exist, and that if a diet does not contain an adequate amount of all of them certain diseases will occur.

Severe shortage of vitamins will lead to the dangerous diseases of scurvy, rickets, pellagra, beri-beri, and others. A slight deficiency may not be followed by serious symptoms, though as a consequence the body may not be in good health.

Many diets in modern civilized communities do not appear to provide an entirely adequate vitamin supply for the body. The addition of an extra pint of milk each day for school-children has been followed in many cases by an increased height and weight, as compared with those who have received the usual diet, which was formerly thought to be adequate in material and energy content.

Our knowledge of the more important vitamins is summarized below; the vitamins are denoted by letters of the alphabet, or by names where their exact composition is known.

Vitamin A. This is abundant in the fat of mammalian and fish livers (*e.g.*, in cod-liver oil), milk, and eggs.

Animals can manufacture vitamin A in their livers, using for this a yellow chemical substance called β-carotene, which is present in carrots and some other sources.

An adequate supply of vitamin A in the diet is essential for healthy growth and to maintain the skin and eyes in a healthy condition. As the skin, particularly that of the throat and nose, prevents disease germs from entering the body, even a slight lack of vitamin A may lead to a decreased resistance to infection.

Severe lack of vitamin A leads to a hardening of the cornea of the eye, a condition known as **xerophthalmia.** Recent research has also shown that poor vision in the dusk, known as '**night-blindness,**' may be due to deficiency of vitamin A.

Vitamin A is not destroyed by heating and keeps well.

Vitamin B. This was once thought to be a single chemical compound, but is now recognized to consist of a complex of six or more separate chemical compounds, each of which probably exerts a separate effect on the body. Two of these are particularly important.

Vitamin B_1 (Aneurin). This is abundant in yeast, in the husks of corn, in wheat and other cereals, and is also found in small amounts in many other foods. Its presence is important because it enables the body to make a proper use of the carbohydrates in the food. It also influences the nervous system.

A severe lack of vitamin B leads to a disease called **beri-beri,** which is characterized by wasting of the muscles, and finally by paralysis.

Vitamin B_1 is not damaged by heating to 100° C. but is destroyed at 120° C. Consequently it is present in dried foods but not in canned foods. Wholemeal bread has fairly large amounts of vitamin B_1, but white bread has little of this vitamin.

Vitamin B_2 (Riboflavin). Yeast, ox-kidney, the yolk of hen's eggs, and milk contain vitamin B_2 in fair quantities. It is essential to cellular respiration.

Nicotinic Acid (the pellagra-preventing vitamin). Until recently that vitamin which prevents the disease called **pellagra** was confused with vitamin B_2. Now it has been identified as nicotinic acid, a compound allied to the drug called nicotine, which is present in small amounts in tobacco.

Nicotinic acid is present in animals' livers in fairly large amounts. Foods which contain vitamin B_1 also contain some, if little, nicotinic acid.

Some of the poorer inhabitants of the United States and Europe cannot afford to buy diets containing adequate amounts of nicotinic acid, and consequently suffer from a condition

called pellagra, with the symptoms of skin disorder and later madness.

Vitamin C (hexuronic or ascorbic acid). Vitamin C is soluble in water and is found chiefly in fresh fruits and vegetables. Oranges and lemons contain fairly large amounts, but the West Indian lime is a poor source of vitamin C. Berries, rose-hips, tomatoes, and certain other vegetables contain this vitamin in fairly large amounts.

Vitamin C appears to play an important part in tissue respiration. Lack of it in the diet has been shown to be followed by a decreased resistance to certain infectious diseases. Absence of it in the diet leads to a condition called **scurvy,** in which the gums become swollen and tend to bleed, together with a general tendency to bleed at other parts of the body.

Considerable losses of vitamin C occur when food is cooked. Four-fifths of the vitamin C present is destroyed by twenty minutes' boiling.

Vitamin D. Vitamin D is soluble in fats but is not abundant in any common food. A fair amount is present in eggs and milk but the best sources are the oils derived from the livers of the fishes cod and halibut. Some animals, including man, manufacture vitamin D in their bodies when they are in sunlight. The ultra-violet rays of the sunlight change a chemical substance called **ergosterol,** which is present in the skin, to vitamin D.

Vitamin D probably helps the body to absorb phosphorus and calcium from food. When there is a lack of vitamin D in the diet we find malformation of bones and teeth. This is especially found in children, whose bones and teeth are still being formed, and where lack of vitamin D leads to a condition called **rickets,** in which the bones are poorly formed.

Research work on vitamins has proceeded rapidly in recent years, and our knowledge is being constantly modified and extended. A great many accessory food factors which have been discovered await more detailed investigation before their importance can be accurately estimated. One of these, named vitamin E, plays an important part in the reproduction of certain animals; there is some indication that an adequate supply of this vitamin may also be essential to human fertility.

Vitamin diseases are clearly not infectious, as they are caused not by bacteria, nor by other parasitic living organisms (see p. 208), but by lack of essential foods.

Vitamin	Disease caused by Severe Deficiency	Best Food Sources	Daily Requirements of Young Child
A	Night-blindness. Xerophthalmia	Butter, egg-yolk, tomato, spinach, cod- and halibut-liver oils	2·5 mgm. (Say 2 oz. of tomatoes, 3 oz. of spinach, or 6 oz. of cabbage.)
B (found as complex of six separate vitamins, B_1, B_2, etc.)	Beri-beri	Wheat, yeast	1–2 mgm. (B_1). (Say one plate of porridge with one pint of milk.)
P.P. factor (nicotinic acid)	Pellagra	Yeast, liver, wheat	20 mgm. (Say 6 oz. of liver or one half-pint of milk.)
C (hexuronic acid)	Scurvy	Oranges, lemons, blackcurrant	50 mgm. (Say one or two oranges.)
D	Rickets	Egg-yolk, butter, cod- and halibut-liver oils	0·05 mgm. (Say 4 oz. of herring.)

N.B. Milk and milk products (butter, cream, dried milk, cheese) and eggs are valuable sources of all the vitamins except C. Babies should be given orange juice where possible. Slight deficiency of any or all vitamins may not lead to definite disease, but will produce poor health.

5. Advances in our Knowledge of Nutrition

Destructive wars or the failures of crops have led to periods of starvation in the past and present. Much of the malnutrition in past centuries may, however, be traced to a lack of certain elements in the diet rather than to a shortage in the bulk of food consumed. The diets of our ancestors often lacked certain vitamins.

Two questions which have often been asked about vitamins show how their nature has been misunderstood by many people. The first question is, "What happened to men before vitamins were discovered?" The second question is, "Shall I feel better if I eat more vitamins?" We shall get some answer to both these questions by a brief study of nutrition in the past and in the present.

In England the food of the country was greatly affected by the changes in industry at the end of the eighteenth century. The movements of the agricultural population to the towns left

fewer people in the countryside to produce food for the nation, and so much food had to be imported. Industrialization in the nineteenth century was attended by a rise in the population of England, and by subsequent poverty in certain classes of the population. Moreover, urbanization was accompanied by a change in the nature of the food consumed by the population. Much of the fresh country food was 'denatured' before it reached the city-dwellers. For example, wholemeal bread became less popular, and its place was taken by white bread, which in comparison contains very little vitamin B_1. In consequence of these changes certain signs of malnutrition directly accountable to vitamin deficiency began to appear in the nation.

However, we should not regard vitamin deficiency as of recent origin. There is abundant evidence of diseases due to vitamin deficiency in early times.

Vitamin A. The earliest reference to vitamin A deficiency is found in an Egyptian manuscript dated about 1500 B.C. A translation reads: "Another prescription for the eyes: liver of ox roasted and pressed, give for it. Very excellent." Night-blindness, due to lack of vitamin A, was also known to the Greeks. It was described by Hippocrates (*c.* 460 B.C.), who correctly prescribed ox-liver in the diet as a remedy for this disease.

Vitamin B_1. The disease beri-beri has probably been known in the East among rice-eating populations for thousands of years, yet no satisfactory explanation of it was given until a naval doctor, Admiral Takaki, investigated the condition in the Japanese Navy. In 1878, 33 per cent. of that navy suffered from beri-beri. Takaki insisted on an improvement in the diet, and by 1888 the disease was almost stamped out.

Later investigations by various workers showed that beri-beri was not due to a lack of proteins, as Takaki had believed, but was found among populations who fed on polished rice, though few cases occurred when the diet contained unpolished rice. We now know that vitamin B_1 is contained near the husk of grain and that the vitamin is removed by the polishing of rice and by the manufacture of white flour. Cases of beri-beri occurring as a result of eating white bread rather than brown or wholemeal bread are rare, but there is little doubt that many of the digestive and nervous ailments of those who cannot afford to buy more expensive foods might be prevented if wholemeal bread were eaten instead of white bread.

The P.P. (Pellagra-preventing) Factor. Pellagra killed more than eleven thousand persons in the United States of America in 1915, and even now thousands of fatal cases occur there every year. Yet this disease can be prevented, and sometimes cured, by a simple alteration of the diet.

The disease was once thought to be infectious, and one might even see illustrations in books of the 'pellagra fly,' which was supposed to carry the disease. Fortunately, an American physician, Dr Joseph Goldberger, was not satisfied with this view, but examined the diets of pellagra victims and found that certain foods were lacking and that even close association with pellagra victims did not cause him or his fellow-workers to 'catch' this disease. He then improved the diets of two orphan asylums and one lunatic asylum where pellagra had been common, and found that no cases occurred after the improvement in diet. Later, convicts in an American gaol were offered freedom if they would live on a diet similar to that 'enjoyed' by pellagra victims; some did, and developed pellagra, so proving that pellagra was not an infectious disease but was due to deficiencies in the diet. Experiments on animals were then employed to identify the anti-pellagra factor in food. This was successful, and deaths from pellagra could now be prevented by correct feeding.

Vitamin C. The value of animal experiments is vividly shown by the discovery of vitamin C.

Scurvy has been known for many hundreds of years. Vasco da Gama sailed round the Cape of Good Hope in 1498 with a crew of 160. A hundred of these perished from scurvy. Admiral Hawkins in 1593 noted about scurvy "that which I have seene most fruitful for this sickness is sower oranges and lemmons." In 1757 a Scottish naval surgeon, called Lind, published a book in which he described careful experiments on the cure of scurvy by oranges and lemons. Eventually, in 1804, the Admiralty took over the control of sailors' health and prescribed that lemon-juice should be carried on ships undertaking long voyages. This led to a great decrease in scurvy in the British Navy. Haslar Naval Hospital admitted 1457 cases of scurvy in 1780, but only one in 1807, after regulations had insisted on precautions against scurvy being undertaken by ships. Even to-day Britishers are referred to by Americans as 'limeys,' a name which is said to refer to the regulation that lemon-juice should be carried by British ships.

It was not, however, until scientists experimented on animals and gave them scurvy by feeding them on diets lacking in certain foods that real progress was made in our knowledge of vitamin C. Many people are appalled by the experiments carried out on living animals and do not appreciate that such experiments are often essential for our knowledge of disease, and that by the suffering and deaths of perhaps a few hundred rats many thousands of human beings can be freed from the ravages of disease. For it is not enough to say, as Hawkins said in the sixteenth century, that scurvy may be cured by sour oranges and lemons. We must examine every symptom of the disease, the possibility of curing it by other methods than oranges and lemons, the extraction of the vitamin as a chemical substance in pure form, and, finally, the preparation of the vitamin by artificial means. These things can only be done by experiments on living animals.

All modern work on scurvy may be said to start with the discovery in 1907 by Norwegian workers that scurvy could be produced in guinea-pigs by certain diets deficient in vitamin C. This enabled other research workers to test the 'anti-scurvy' properties of their extracts of orange-juice. Eventually workers in England and Germany noticed that fresh fruit juice cured scurvy, but stale fruit juice did not. Furthermore, it was observed that an acid, hexuronic acid ($C_6H_8O_6$), also disappeared from fruit juice as it became stale. The final identification of hexuronic acid with vitamin C was accomplished by a Hungarian, Szent-Györgyi, who fed this acid to guinea-pigs and cured them of scurvy. Vitamin C was later prepared in the laboratory. But for the experiments on animals the discovery and isolation of vitamin C might never have been made.

Vitamin D. In 1650 an English professor described the disease rickets, but it was not until the nineteenth century that cures for rickets were proposed. In 1890 it was shown that sunlight prevented severe rickets, and by 1932 vitamin D had been analysed in the laboratory. The malnutrition in Germany and Austria in 1919 stimulated work on rickets. It was impossible to provide foods rich in vitamin D for the many thousands of children suffering from rickets in those countries. Sunlight was therefore tried, and found to aid the cure in most cases.

Although cases of severe rickets are fairly rare to-day in our cities, there is still room for improvement. In 1868 one-third of

London's children suffered from severe rickets. In 1928 an examination of London children showed few cases of severe rickets, but four-fifths of the schoolchildren examined showed traces.

Recent Improvements in Nutrition. There is little doubt that our national health has improved since about 1870. During recruiting for the Boer War (1899–1902) about 40 per cent. of the volunteers were rejected on account of their poor health. In the War of 1914 the proportion of medically unfit men was much less, while in the war that began in 1939 less than 10 per cent. of the conscripts were rejected for medical reasons.

An increased consumption of the foods rich in the 'protective' vitamins may have played an important role in the improvement of the nation's health. A comparison of the consumption of certain foods illustrates this.

CONSUMPTION PER HEAD IN LB. PER YEAR

	WHEAT	POTATOES	SUGAR	MEAT	BUTTER	FRUIT	VEGETABLES
1911–13 .	211	208	79	135	16	61	60
1936 . .	212	213	94	148	25	114	126

This table shows that more food is being eaten by the nation, particularly more of those which are rich in vitamins.

The consumption of milk has also increased, owing largely to the activities of the National Milk Marketing Board, yet it is still too low. The average consumption per head of milk is only one-third of a pint per day. A consumption very many times as great would benefit the nation.

The present consumption of bread is also unsatisfactory. In the past hundred years the average daily consumption per head has dropped from 21·3 ounces of wholemeal bread in 1840 to 11·6 ounces of white bread in 1934, the latter representing one-tenth of the vitamin B content of the 1840 diet. Probably other foods replace most of this vitamin B, but there is no doubt that the nation's health would be improved if more wholemeal bread were eaten.

If a person's diet is fairly rich in milk, vegetables, and other 'protective' foods probably little or no improvement in health would be obtained by consuming vitamins in the form of cod-liver oils or other medicines. It is probable, however, that few

of us eat a diet which is so well balanced as to allow us a proper supply of vitamins.

We may emphasize this last statement by concluding with an account of an experiment on nutrition performed by Major-General Sir Robert McCarrison. Sir Robert took forty healthy young rats and divided them into two equal lots. For the next six months he fed the two batches on different diets. One batch received milk, fruit, and green vegetables; the other received a diet of white bread, a substitute for margarine, tinned meat, tinned jam, vegetables cooked in soda, and tea with very little milk and sugar. The rats were kept in clean cages and enjoyed plenty of sunlight.

At the end of six months their condition was recorded. Only three of those who had been reared on the good diet of fresh food were dead—one by an injury, one by pneumonia, and one through no apparent cause. The remaining rats on this diet were fat, active, and with sleek coats. Those rats which had survived on the poor diet were all thin, weak, and with poor coats of fur. Nine of the original twenty had died, some from pneumonia and some from weakness. All the dead rats were found to have diseases of the digestive system.

Authorities have estimated that nearly half of the population consume diets little better than that given to the second group of rats. Some families consume artificial rather than natural foods by choice, but most malnutrition can be traced to poverty, which does not permit the purchase of protective foods rich in vitamins. Yet experts have estimated that enough vitamin D to protect every child in the country would only cost £100,000 per year, and that an adequate milk supply for every child under fourteen would cost only £6,000,000 yearly.[1] There is no doubt that the results would justify the claim that the science of nutrition is one of the leading sciences of this century, and that the destinies of nations depend on the manner in which they are nourished.

SUMMARY

(1) Most of the food which we consume is balanced by an equivalent amount of material which our bodies excrete. Our weight does not therefore greatly increase after each meal.

(2) Food contains potential energy. Any kinetic energy which

[1] 1940 estimates.

is used in our daily activities is balanced by the potential energy which we take in our food.

(3) Certain chemical elements are required by the body in fairly large amounts to build protoplasm.

(4) Minute amounts of chemical substances called vitamins must be present in our food if we are to remain healthy.

(5) A satisfactory diet should be so balanced that it supplies potential energy and all the chemical substances required by the body—namely, water, proteins, carbohydrates, fats, mineral salts, and vitamins.

SUGGESTIONS FOR HOME STUDY

(1) Plan a diet-sheet for one day, choosing inexpensive foods but taking care to meet the full food requirements of a child.

(2) "What happened to men before vitamins were discovered?" Discuss this question.

CHAPTER IX

DIGESTION

Now good digestion wait on appetite,
And health on both!

W. SHAKESPEARE, *Macbeth*

1. PURPOSE AND METHOD OF DIGESTION

WE may now examine the fate of the food after it has entered the body. To help our study let us consider what happens to our breakfast when we have eaten it.

ANALYSIS OF A GOOD BREAKFAST

FOOD	PROTEINS (PERCENTAGE)	CARBOHYDRATES (PERCENTAGE)	FATS (PERCENTAGE)	CALORIES PER LB.	VITAMINS
Oatmeal porridge	11·9	70·0	8·6	1885	A + (*i.e.*, only a moderate amount present) B ++
Bacon . .	9·0	Negligible	55·2	2492	—
Egg . . .	12·4	0·7	11·5	81 (1 egg)	A ++ B ++ D ++
White bread .	8·9	54·0	0·3	1182	—
Butter . .	0·2	None	83·0	3497	A+++ (*i.e.*, rich in Vitamin A) D +++
Coffee or tea .		NO FOOD VALUE			
Milk . .	3·4	4·8	3·5	376 per pint	A ++ B + D ++

The foods contain water and mineral salts in addition to the compounds given above.

Most of our foods are solid, and must be made soluble before they can be absorbed by the body. Even apparently soluble foods, like milk, must generally undergo chemical change before they can be used by the body.

The breaking down of foodstuffs and their conversion to

chemical substances which can be absorbed by the body is performed during a process called **digestion.**

2. Man's Digestive System

The digestive systems of man and other vertebrates are built on a common plan. Food passes down a long tube, the **alimen-**

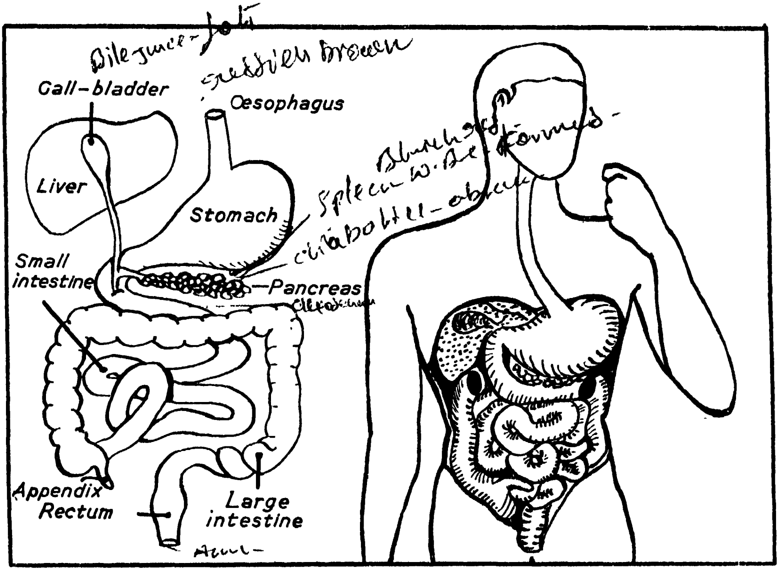

FIG. 39. DIAGRAM TO ILLUSTRATE THE MAIN FEATURES OF THE HUMAN DIGESTIVE SYSTEM AND THE POSITION OF SOME OF THE DIGESTIVE ORGANS IN THE BODY

tary canal (L., *alere*, to nourish), of which various regions are modified for particular activities.

Before passing down the alimentary canal of man food is broken into smaller pieces by the teeth in the mouth; it is then passed down a tube, the **œsophagus** (Gk., *oisophagos*, gullet) to the **stomach,** where it is retained for some hours. Thence the food passes slowly down the **duodenum** (L., *duodeni*, twelve each), where it is acted on by many digestive enzymes. It then travels down the **intestine,** in which most of the digested food is absorbed by the walls. What remains of the man's last few meals then collects in the **rectum** (L., *rectus*, straight), and is later passed out to the exterior as excretory material through a hole in the body-wall, the **anus** (L., *anus*, ring).

This brief and incomplete survey of the processes of digestion in man, together with reference to Fig. 39, provides an introduction to a more detailed study of the process, which is a complicated one and involves the action of many digestive enzymes. These enzymes are chemical compounds which promote chemical reactions whereby the food is made more soluble.

The outer walls of the alimentary canal are muscular, and by their waves of expansion and contraction, called **peristaltic** movements (Gk., *peri*, round; *stellein*, to place), food is gently forced through the alimentary canal, and so passes from one region of the canal to the next; the inner walls of the alimentary canal contain tissues called **glands,** which manufacture the **digestive juices.** These contain digestive enzymes in which the food is bathed as it passes through the digestive system.

3. Digestion

The digestive enzymes bring about changes in the chemical substances present in food, making their contained molecules smaller, and so more easily absorbed by the body.

The Mouth. In the mouth a digestive juice is prepared by three pairs of glands, the **salivary glands,** which are situated near the hinges of the jaws. The saliva which they produce helps to moisten the food and to lubricate its passage down the alimentary canal, and it also starts digestion by means of an enzyme which it contains, called **ptyalin.** This enzyme acts on starch and converts it into soluble sugars. These, and the undigested material, pass through the œsophagus to the stomach.

The Stomach. In the stomach food is acted on by two main chemical substances: (i) **hydrochloric acid** (about 0·2 to 0·5 per cent.), which stops the action of ptyalin and kills any bacteria in the food; (ii) **pepsin,** an enzyme which breaks down the complicated protein molecules into simpler ones, known as **peptones** and **proteoses.**

Another enzyme, called **rennin,** coagulates milk, thus preventing it passing too rapidly through the alimentary canal before it can be digested.

Food takes from three to four hours to pass through the stomach. Muscles in the stomach wall continually move so that the food is mashed and soaked in the digestive juices. The food slowly passes from the stomach into a coiled tube. the **duodenum ;**

the exit of the food from the stomach is controlled by a circular muscle called a **sphincter** (Gk., *sphingein*, to bind tightly). In the duodenum the food is acted on by many digestive juices manufactured by a gland, the **pancreas** (which a butcher calls 'sweetbreads'). The pancreatic juice contains three enzymes:

(1) **Trypsin.** An enzyme which continues the digestion of proteins and peptones by breaking down peptones, proteoses, and any remaining proteins into **amino-acids,** which are chemicals which have still smaller molecules than have peptones.

(2) **Amylase.** An enzyme which converts undigested starch into maltose sugar.

(3) **Lipase.** An enzyme which acts on fats, converting them into **fatty acids** and **glycerol** (soluble products which can pass through the intestinal wall). The digestion of fats is aided by a green fluid called the **bile,** which is made by the liver, stored in the **gall-bladder** (a gland embedded in the liver), and carried to the duodenum along the bile-duct. Bile breaks up the fats into fine droplets, which can be easily acted on by lipase. This process is called the emulsification of fats.

After the food has been acted on by the pancreatic juice it passes into a long, coiled tube, the small intestine, where other enzymes complete the digestion of sugars and proteins. The small intestine is also the region for the absorption of food, and here the small molecules of amino-acids, sugar, etc., pass through the walls of the intestine into the blood, and are carried to the liver.

After the food has passed through the small intestine it may enter the large intestine, where water is absorbed, or it may enter a 'blind alley,' the **cæcum** (L., *cæcus*, blind), which terminates in the **vermiform appendix** (L., *vermis*, worm; *forma*, shape). In animals which eat a great deal of plant food the cæcum is large, and is filled with bacteria which can digest cellulose, the carbohydrate which forms the cell-walls of plants. The rabbit has a large cæcum, but man, who eats less plant food, has a very much smaller cæcum and an appendix (L., *ad*, to; *pendere*, to hang), which has little function and may even be troublesome. Sometimes an appendix becomes inflamed and produces poisons which cause a disease known as appendicitis, which can be cured by removal of the appendix or by careful dieting in mild cases.

5. The Teeth

The chewing, or mastication, of our food is a necessary preliminary to digestion, for by it the food is ground into fine particles on which the digestive enzymes can act easily. Care of

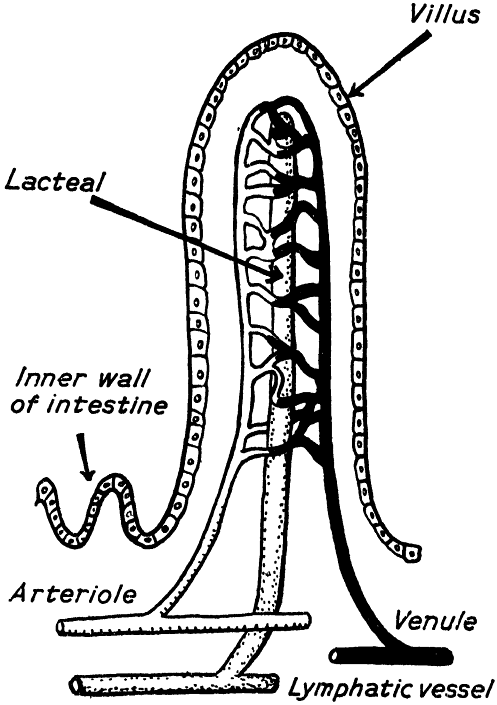

Fig. 41. Blood-supply of the Small Intestine
A single villus is shown in section, with the blood vessels which supply it.

the teeth and thorough mastication therefore increase the value of our food.

Each tooth has the same basic plan—a cap of **enamel** protects a block of **dentine** (L., *dens*, tooth) which surrounds a central pulp cavity. The cap of enamel is very hard, and formed of a bone-like substance which often forms small projections called **cusps** (L., *cuspis*, point). The dentine is softer, and is penetrated by many fine nerves, which transmit a message of pain to the brain as the dentist drills through dentine when filling a hole in a tooth. The central pulp-cavity is soft, and very well supplied with blood vessels and nerves.

Long roots of the tooth are embedded in the jaw and fixed there by a cement-like substance.

The accumulation of foodstuffs in the cracks between teeth or between cusps often leads to the formation there of chemical substances which dissolve the enamel and thereby allow germs to enter and cause decay. Decayed teeth produce mild poisons,

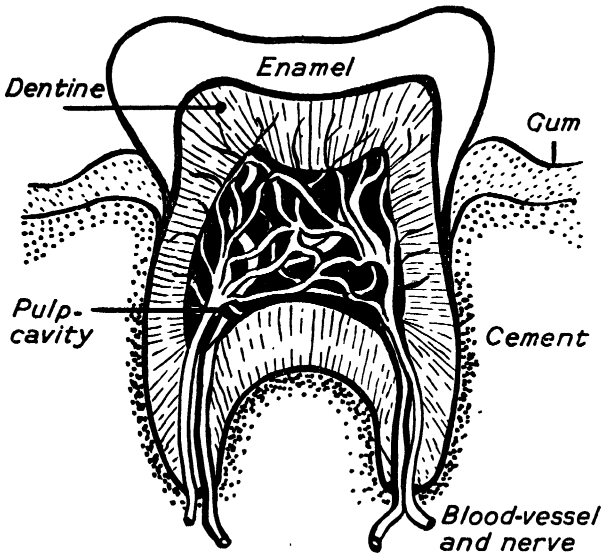

FIG. 42. VERTICAL SECTION OF A HUMAN TOOTH, SHOWN EMBEDDED IN THE GUM

which lower the body's health. Frequent brushing of the teeth keeps them healthy.

Teeth vary in different animals. In the simpler vertebrates they are usually all similar and peg-like, but in mammals they may vary in shape according to the type of food eaten by the species. Fundamentally, there are three types of teeth in a mammalian jaw. In front there are chisel-shaped **incisors** (L., *incisus*, cut into), which are used for nibbling, then single, pointed **canines** (L., *canis*, dog), which are used for biting and tearing, and finally flat **molars** (L., *molere*, to grind), which are used for grinding food. Animals, like the rabbit, which feed on grass and shoots have well-developed incisors for nibbling and molars for grinding, but no canines. Flesh-eating animals, such as tigers, wolves, and dogs, have full sets of teeth, with especially long, sharp canines and sharp points on the molars for tearing

flesh. We have a complete set of teeth, capable of dealing with animal or vegetable food; the teeth are neither very sharp for flesh-eating, nor flat or deeply ridged for grinding plants, but moderately flat, with small, sharp points, or cusps.

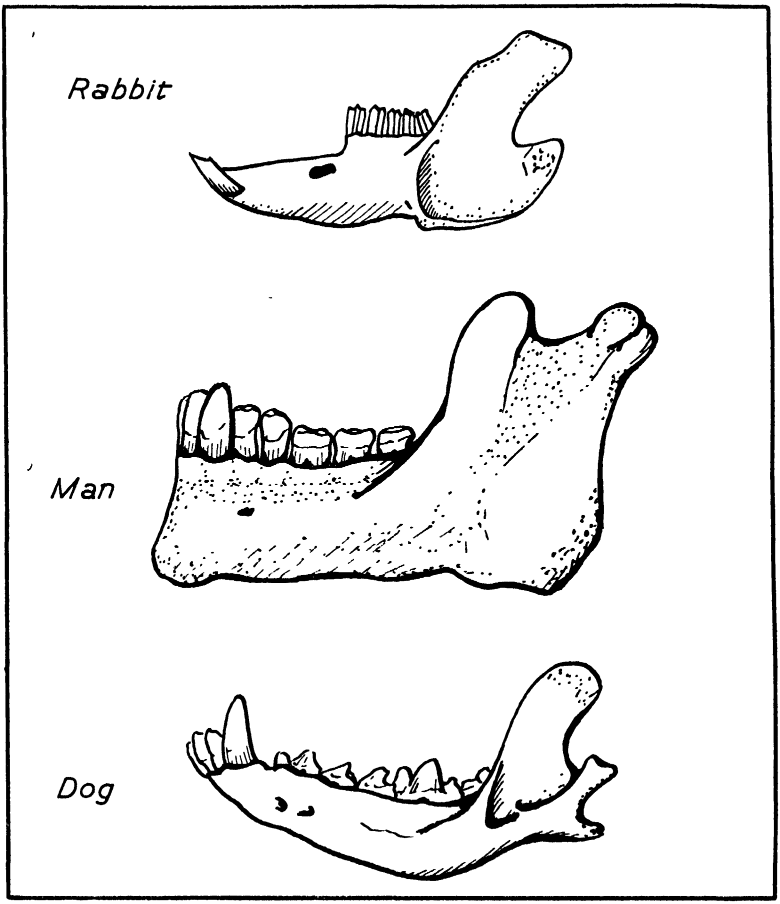

FIG. 43. JAWS OF A HERBIVORE (RABBIT), CARNIVORE (DOG), AND OMNIVORE (MAN) COMPARED

The figures have been drawn the same size for ease in comparison and are not to scale.

The adult teeth of mammals are preceded by a first set of 'milk-teeth,' which we shed in the early years of our lives. A few large teeth, the true molars, are not preceded by milk-teeth, but develop later at maturity. These true molars should be distinguished from the **premolars,** which also have a grinding

surface but which arise first as milk-teeth. The last molars to appear are the wisdom-teeth, which are set so far back on the jaws that they cannot grind food, and generally decay. They are a relic of man's ancestors, who had longer jaws than modern man (p. 281).

THE PRINCIPAL ENZYMES IN THE DIGESTIVE CANAL OF MAN

NAME AND POSITION OF GLAND	ENZYMES IN SECRETION	ACTIONS OF ENZYMES ON FOOD
Salivary glands (near mouth)	Ptyalin	Acts on starch to form malt-sugar (maltose)
Stomach wall	Pepsin	Converts proteins to proteoses and peptones
	Rennin	Acts on casein, the protein in milk, and thus 'clots' milk
Pancreas (near duodenum)	Amylase	Converts starch into maltose
	Trypsin	Converts proteins to proteoses, peptones, and amino-acids
	Lipase	Converts fats to glycerol and fatty acids
Glands in walls of small intestine	Erepsin	Converts proteoses and peptones to amino-acids
	Maltase	Converts maltose to glucose

SUMMARY

(1) Before the food of animals can be absorbed by the body it must be made soluble, so that it can pass through the walls of the alimentary canal; this process is called digestion.

(2) Chemical substances called enzymes cause reactions to occur by which foodstuffs are broken down and made soluble.

(3) Food is absorbed by blood-vessels in the walls of the alimentary canal and carried in the blood to the parts of the body which need food.

(4) Teeth crush our food before it enters the digestive system. The teeth of animals vary in form with the type of food which they consume.

SUGGESTIONS FOR HOME STUDY

(1) Where and how are (*a*) bread, (*b*) fat and lean meat, digested in our body?

(2) Describe the structure and the function of animals' teeth in relation to their food.

PART II

CHAPTER X

RESPIRATION

Shall man into the mystery of breath
From his quick beating pulse a pathway spy?
G. MEREDITH, *Hymn to Colour*

WHEN we place an animal in a calorimeter we find that the amounts of the oxygen breathed in by the animal and of the carbon dioxide breathed out are related to one another. They are, moreover, related to the energy the body releases and to the food it consumes. It is not surprising, therefore, to find that the interchange of oxygen and carbon dioxide between living things and their surroundings is part of a process whereby energy is released from the breakdown of chemical substances. In animals these substances are replaced by the food which they eat.

The breakdown of chemical substances in organisms with a release of energy is called **respiration** (L., *re*, again; *spirare*, to breathe).

1. RESPIRATION AND COMBUSTION

There are superficial resemblances between the respiration process in our bodies and the burning of wood in a fire to give heat. In both processes complex substances are broken down, oxygen is absorbed, carbon dioxide is given off, and energy may be released as heat.

The early chemists were aware that a process something like combustion takes place in our bodies. The experiments of Priestley (1733–1804) had shown that when red mercuric oxide is heated very strongly a gas is produced. Lavoisier (1743–94) realized that this gas was probably the same as that which is present in air and combines with mercury to form mercuric oxide when mercury is burnt in air. He called this gas oxygen, and showed that it combines with metals when they are burnt.

Lavoisier later turned his attention to the breathing of animals, which he recognized to be an oxidation process of a kind essentially similar to the burning of a candle flame. He showed that carbon dioxide and water are produced as we breathe and that

oxygen is taken into the body during the process. He concluded, moreover, that the heat of our bodies is a result of respiration.

Subsequent work has shown that, while respiration, involving as it does a number of chemical reactions, is a more complex process than the simple combustion of materials, the processes of respiration and combustion are in broad outline similar. In both processes complex chemical compounds are broken down, oxygen is taken in, carbon dioxide is given off, and energy is released.

2. Respiration in Plants

Respiration may be studied conveniently in plants, where the process is a relatively simple one, not complicated by special respiratory organs or a circulatory system, as it is in animals.

Our evidence from experiments suggests that when a plant respires it breaks down the sugars which it has built up by photosynthesis, and so obtains energy for its activities. The reaction is probably a complex one involving many stages, but it is possible to construct an equation which indicates simply the main features of the process in **plants or animals.**

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + 677 \text{ kg. cals.}$$

Translated into words, this equation indicates that if complete respiration occurs a molecule of sugar will combine with six molecules of oxygen to form six molecules of carbon dioxide and six molecules of water, liberating enough energy in the process to raise 677,000 grammes of water through a temperature of one degree centigrade.

As mentioned above, this reaction probably takes place in a number of stages, which are activated and controlled by enzymes. Moreover, in many cases the amount of sugar consumed during respiration is greater than the amount of carbon dioxide actually released, thus suggesting that one function of respiration is the production of chemical substances that are intermediate between sugars and the final products (see p. 233).

Nevertheless, in spite of these qualifying statements, we may for the moment regard plant respiration simply as a process consisting of the breaking down of sugars and the release of the energy which they contain. Some of this energy is used by the plant during growth and is instrumental in making shoots rise upward against the force of gravity and in forcing roots into the

soil against the friction of the soil particles; energy is also required in chemical reactions which involve the building of complex chemical substances, such as the proteins in the plant tissues. The energy not used by the plant is dissipated as heat.

The process of plant respiration, including as it does the absorption of oxygen, the release of heat energy, and the production of

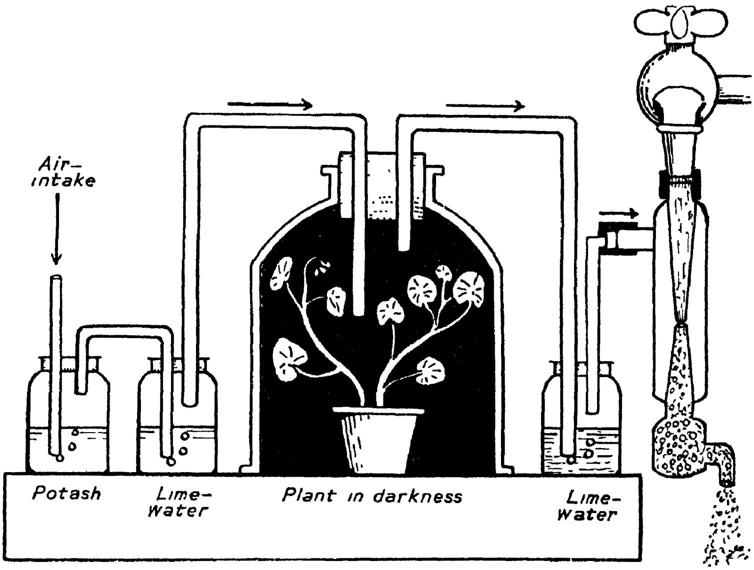

FIG. 44. EXPERIMENT TO SHOW THAT A PLANT RESPIRES, GIVING OFF CARBON DIOXIDE IN DARKNESS

The pot in which the plant is rooted should be covered with a gas-proof material to prevent interchange of gases between the soil in the pot and the surrounding air. Air is drawn through the apparatus by the water-pump; the lime-water in the right-hand flask becomes cloudy. (See also Fig. 35.)

carbon dioxide, can be demonstrated experimentally. (See experiment at p. 20 and Fig. 44 respectively.) It should be noted that respiration in an adult plant is only apparent in this way when the plant is in darkness; in light the rate of photosynthesis exceeds that of respiration, and so carbon dioxide is absorbed by the plant and oxygen is given off.

Yet respiration is constantly occurring in the plant's cells. In light the oxygen used is supplied by photosynthesis, while in darkness the oxygen is taken in through the stomata in the leaves and some carbon dioxide passes out through the same channels.

In summarizing the process of plant respiration we can therefore divide it into two stages: (1) **tissue respiration,** involving

the breaking down of sugars in tissues, together with a release of energy, and (2) **body respiration,** which we may define as an interchange of gases between the plant and its surrounding medium (*i.e.*, air or water). We shall find that respiration in animals is an essentially similar process.

3. Respiration in Lower Animals

The respiration of animals is essentially similar to that of plants, but in most animals certain tissues are specialized to form organs which absorb the oxygen from the atmosphere and from which carbon dioxide is lost to the atmosphere. In ourselves the **lungs** (Fig. 47) function as organs of respiration.

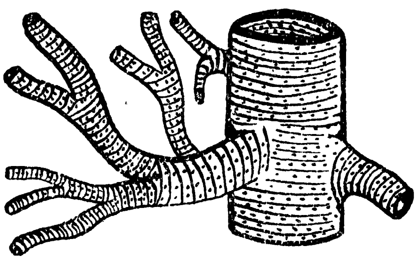

Fig. 45. Small Portion of the Tracheal System of an Insect

Where respiratory organs are present in an animal the oxygen and carbon dioxide are usually carried to the tissues by the **blood.**

Earthworms. Earthworms have no special respiratory organs, but respire through their skins. The skin is liberally supplied with blood-vessels, which collect the oxygen that soaks through the skin; the ventral surface is particularly well supplied with these. The skin must be kept moist in earthworms in order that they may breathe. (See Fig. 3.)

Insects. A system of innumerable fine tubes supplies almost every cell in the insect's body with oxygen and carries away the carbon dioxide. The tubes are known as **tracheal tubes;** they open to the exterior at various points on the skin through small pores called **spiracles** (Plate 6). Each spiracle is provided with hairs, which exclude dust, and with two lips which can close the opening. The muscular activities of the insect, such as wing movements, aid the diffusion of air along the tracheæ, but in spite of this the rate of diffusion is slow.

Fish. Respiration is effected in fish by means of **gills,** which are slits connecting the pharynx with the water in which the fish lives. As the fish moves along water in which air is dissolved passes into the mouth, down the pharynx, and thence out through the gill-slits. The gill-slits are lined with feathery flaps of skin,

called the gills, which are well supplied with blood-vessels. As water passes over the gills, therefore, dissolved oxygen from it enters the blood of the fish, while carbon dioxide comes out.

When a fish is taken out of water it dies, since the gills become dry and respiration cannot occur.

Amphibians, reptiles, birds, and mammals. The terrestrial vertebrates breathe by means of **lungs,** which consist of spongy sacs well supplied with blood-vessels.

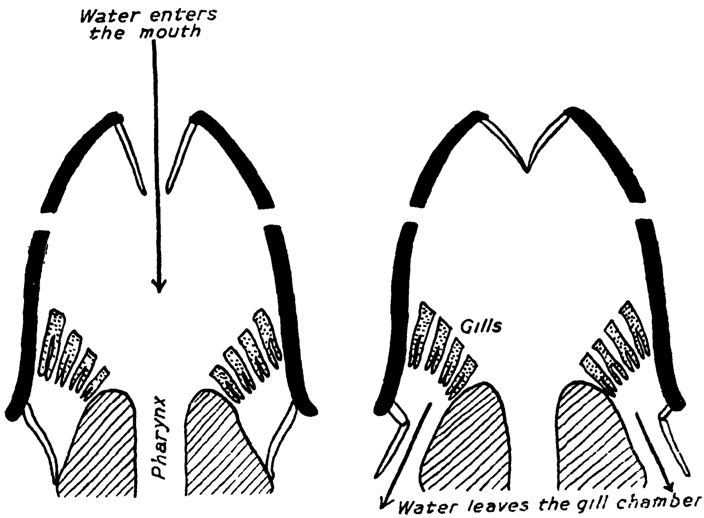

FIG. 46. DIAGRAM TO SHOW THE MECHANISM OF RESPIRATION IN A BONY FISH

The anterior part of the mouth cavity is shown in vertical section, the posterior part in horizontal section. The figures are redrawn after Dahlgren.

4. RESPIRATION IN MAN

When we breathe air passes through the nose, down the throat, and into the chest, where it fills the two large sacs called **lungs.** When we breathe out 'air' returns through the throat and the nose and is expelled. Experiments have shown that the air which we inhale is a mixture composed mainly of the gases nitrogen and oxygen, but that the 'air' which we exhale has carbon dioxide in place of the oxygen. An interchange of oxygen and carbon dioxide has taken place in the lungs.

Each lung is filled with a number of minute separated cavities, the **alveoli** (L., *alveolus*, small pit), which communicate with a tube, the **bronchus** (Gk., *bronchos*, wind-pipe). The two bronchi

join to form a single tube called the **trachea** (L., *trachia*, windpipe).

The lungs are contained in a cavity called the **pleural cavity** (Gk., *pleura*, side), which is enclosed on one side by a sheet of muscle, the **diaphragm** (Gk., *diaphragma*, midriff), and bounded on other sides by the ribs.

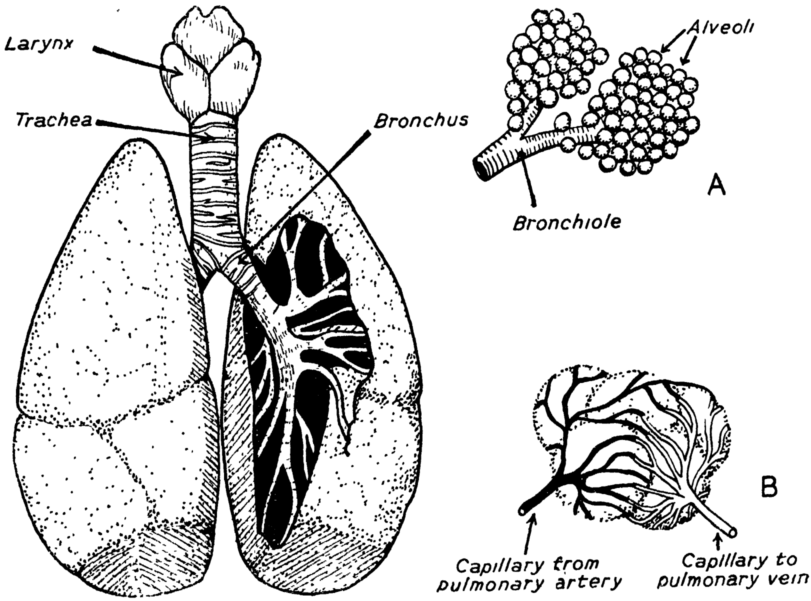

FIG. 47. SEMI-DIAGRAMMATIC VIEW OF A HUMAN LUNG

The lung is shown cut open on the man's left side to reveal the internal arrangement of the bronchioles. *A*, the alveoli, showing their relationship to a bronchiole; *B*, an enlarged view of five alveoli, showing how they are supplied by fine capillaries of the blood system.

Respiration takes place in three stages:

(1) When the diaphragm contracts and the ribs are raised by the action of the intercostal muscles (L., *inter*, between; *costas*, rib) the volume of the pleural cavity enlarges. The pressure inside the pleural cavity is therefore less than the pressure of the atmosphere, and air rushes into the lungs, which expand to fill the pleural cavity, so equalizing the pressure. This process is called **inspiration.**

(2) Fresh air now fills the alveoli, the walls of which are richly supplied with fine blood-vessels. As the blood passes along these vessels oxygen diffuses from the cavities of the alveoli into the blood; at the same time carbon dioxide passes from the blood into the alveoli.

The absorptive surface of the alveoli is great. If all the air-sacs in the lung of a normal man could be laid out flat they would occupy a surface of about a hundred square yards, or about the area of the walls and ceiling of a fairly large sitting-room.

(3) The compression of the lungs by the lowering of the ribs and the relaxation of the diaphragm forces the air out of the lungs, and so effects the process of **expiration.**

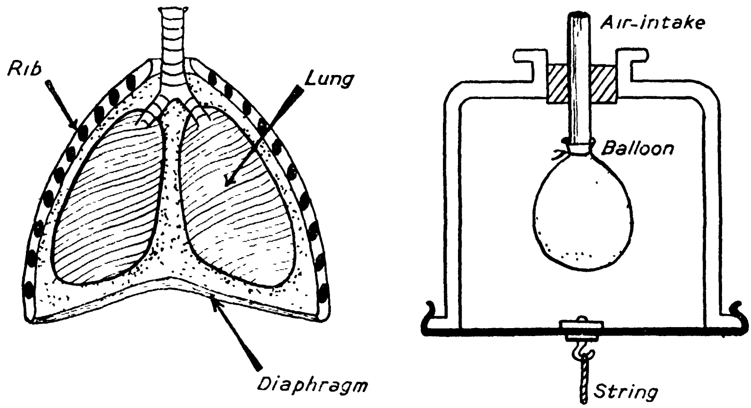

FIG. 48. DIAGRAMS TO SHOW THE RELATION OF THE HUMAN LUNG TO THE RIBS AND THE WORKING OF THE THORAX AND LUNGS

In the apparatus shown on the right, tension on the string, by distending the rubber membrane, diminishes the pressure of air within the bell-jar and so the balloon expands, thus drawing in air through the glass tube.

5. RESPIRATION, EXERCISE, AND VENTILATION

We must remember that respiration in the lungs is only one stage in the respiration of man, since the oxygen which so enters the body passes in the blood to all the cells of the body, where tissue respiration occurs. The amount of oxygen absorbed by the lungs will therefore depend on the rate of tissue respiration, and, conversely, the rate of tissue respiration will be affected by the amount of oxygen absorbed by the lungs.

The oxygen consumption of a man may be measured by means of an apparatus so constituted that the valves allow air to be inspired, while the expired gases are collected in an india-rubber fabric bag. After a given time the gases in the bag can be chemically analysed and their volume determined. The data provided by Professor Sir A. V. Hill[1] illustrate the relation between oxygen consumption and exercise.

[1] *Living Machinery* (Bell, 1927).

Hill tested his own oxygen consumption and found that while standing still he consumed 0·35 litres per minute; walking at 2 miles an hour raised this consumption to 0·55 litres per minute; at $3\frac{1}{2}$ miles per hour 1·06 litres per minute were used; walking at 5 miles per hour required 2·25 litres a minute. It is therefore apparent that as we move faster we breathe more rapidly, and at the same time respire in an uneconomical way. By going faster we save time but burn proportionately more fuel.

Oxygen consumption experiments also emphasize that our activities are governed to some extent by the 'freshness' of the air which we breathe. In a small room containing many people the oxygen will gradually be consumed and replaced by carbon dioxide, the tissue respiration rates of the occupants will diminish, and they will feel tired, sleepy, and possibly get severe headaches. Ventilation of rooms is therefore a necessity, even though it may cause the room to become cooler.

6. The Carbon Cycle

In order to summarize the important aspects of respiration we must examine the stages in the energy-changes which take place in living things.

(1) All the energy of living things is ultimately derived from sunlight.

(2) Sunlight enables plants to manufacture organic chemical substances from carbon dioxide, water, and salts.

(3) Organic chemical substances therefore contain a store of energy in the form known as potential energy (*i.e.*, energy which is not doing work but which is capable of doing it—such energy as is present in a coiled watch-spring or a charged battery).

(4) The potential energy in organic chemicals may be converted into **kinetic** energy (*i.e.*, energy which is doing work) if the organic chemicals are 'burnt' in respiration.

It should be noted through a comparison of the equations for respiration and photosynthesis that the element carbon makes a circulation in nature from animals to plants and back again to animals. The carbon dioxide breathed out by animals is absorbed by the plant and is used in the manufacture of carbohydrates. These carbon chemicals are eaten by animals and the stores of energy present in them used, while the carbon is subsequently returned to the atmosphere by being breathed out in the

form of carbon dioxide. Animals and plants are thus mutually dependent on one another, the animals depending on the plants for oxygen and food and the plants depending to some extent on the animals for carbon dioxide.

The animals and plants on the earth keep the proportions of oxygen and carbon dioxide in the air moderately constant, the extremes being found in city air, in which the proportion of carbon dioxide is high, and in forest air, which contains little carbon dioxide but much oxygen.

The parks of London are sometimes called the 'lungs' of the city, as the green plants in them convert the fetid air, which is full of carbon dioxide, into clean oxygenated air.

SUMMARY

(1) Animals and plants breathe by taking in oxygen and giving out carbon dioxide.

(2) In the body tissues the oxygen is involved in a chemical reaction in which sugar is transformed into simpler substances and energy is released.

(3) The element carbon is in plants built up into carbohydrates during photosynthesis and released as carbon dioxide when respiration occurs. There is, therefore, a circulation of carbon in nature.

(4) Our activities are governed by our rate of respiration. Fresh air and good ventilation are therefore essential.

SUGGESTIONS FOR HOME STUDY

(1) Describe the process of respiration in man and explain why it occurs.

(2) Compare respiration in a plant, an earthworm, a fish, and a man.

CHAPTER XI

TRANSPORT

I have not endeavoured from causes and probable principles to demonstrate my propositions, but to establish them by appeals to sense and experiment.

WILLIAM HARVEY, *Anatomical Disquisition* (1628)

A SYSTEM of tubes carries chemical substances round the bodies of many animals and many plants. In ourselves the **blood-circulatory system** transports substances round the body.

1. TRANSPORT IN PLANTS

Water and other food materials, together with the products of photosynthesis, are conveyed from one part of a plant to another by conducting tissues called **vascular** tissues (L., *vasculum*, small vessel). Two types of tissue can be distinguished, and are known as the **xylem** (Gk., *xylon*, wood) and the **phlöem** (Gk., *phloios*, smooth bark).

There is evidence that the xylem provides a channel for the passage of water from the root to the leaves during the process of transpiration (p. 73). If cut shoots of plants are dipped in red ink the ink will be drawn by transpiration to the leaves and sections cut through the stem will show that only the xylem tissues are stained by the ink. Moreover, if a short portion of a stem is stripped of its bark and the soft tissues (cortex and phloem) directly beneath it will continue to transpire as before.

The position of the xylem in relation to the other tissues is shown by Figs. 49 and 80. Reference to these figures also shows that in trees the increase in girth is due mainly to an increase of xylem tissue, which is also known as **wood.**

Xylem tissue is composed mainly of cells which have lost their protoplasmic contents and whose walls have become greatly strengthened by the addition of a chemical substance called **lignin** (L., *lignum*, wood). Strictly, therefore, the xylem tissues are not living tissues, since they are little more than tubes the walls of which are composed mainly of lignin.

Phloem tissues are believed to conduct sugars and other soluble organic materials from one part of the plant to another. Thus,

when sugar is manufactured in the leaves of a potato it is probably carried through the phloem to the underground tubers, where it is stored as starch. The phloem cells, unlike xylem tissues, contain living protoplasm; they are separated from one another by perforated plates called **sieve-plates,** through which protoplasm can pass. The main phloem cells are called sieve-tubes. Associ-

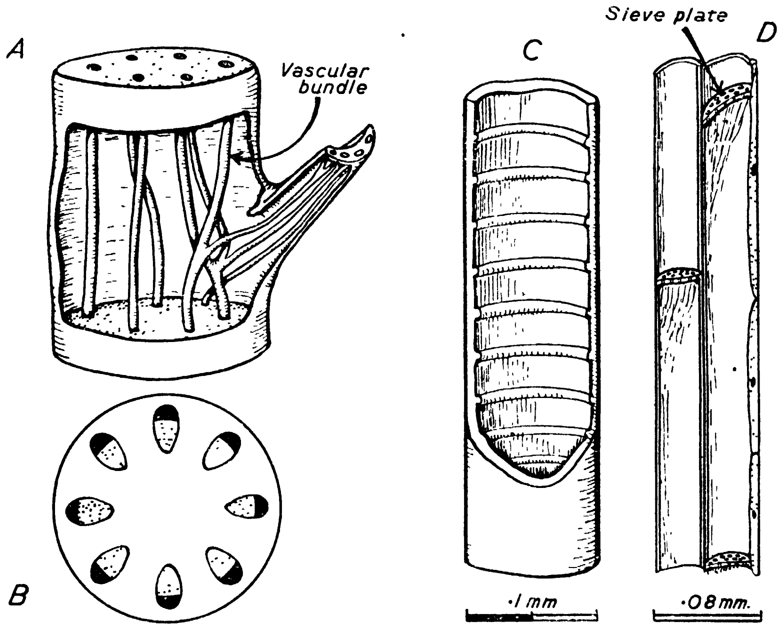

FIG. 49. CONDUCTING TISSUES IN PLANTS

A, the internal arrangement of the primary vascular system in a small portion of the stem of *Solanum tuberosum*, the potato; *B*, a cross-section of a similar stem, in which Xylem tissues are stipple-shaded and the Phloem tissues black; *C*, a single Xylem vessel, opened to show one method of strengthening by the thickening of the walls with rings of lignin; *D*, a vertical section through a few Phloem cells. Figure *A* is redrawn after Artschwager.

ated with them we find narrow, unspecialized cells called **companion cells.**

The tissues of xylem and phloem are generally placed near to each other in plants and together form vascular bundles in the root, stem, and leaves. In the leaves the vascular tissues become finely divided and branch, so forming the 'veins.'

2. THE STRUCTURE AND ORIGIN OF BLOOD

Blood is a fluid which bathes the tissues of animals' bodies; it is constantly circulating and so transports materials from one

part of the body to another. In some animals it is almost colourless, in others it is pale blue or red.

If a drop of human blood is placed on a glass slide and examined with a microscope it is seen to consist of a pale yellow fluid in which a number of cells float; this fluid portion is called the **plasma,** and the cells, of which there are several varieties, are called **corpuscles.** The various constituents of blood possess different functions.

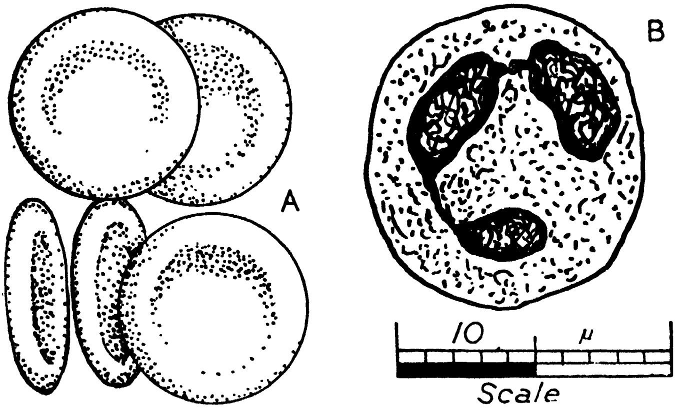

FIG. 50. FIVE RED CORPUSCLES AND ONE WHITE CORPUSCLE FROM HUMAN BLOOD

The plasma carries dissolved food materials, excretory products chemical regulators, and other materials. The corpuscles are of two main types, red and white. The former transport oxygen from the lungs to the rest of the body; the latter are mainly concerned with protective functions.

The figures below give some idea of the amounts and proportions of the constituents of blood in a human body:

In a human body there is
about nine pints of blood.

Each cubic millimetre contains about five million red corpuscles and about seven thousand white corpuscles.

Each red corpuscle is on the average 7–8μ in diameter; the white corpuscles are 10–12μ, sometimes more.

Red Corpuscles (Plate 7). These cells are formed principally in

the red marrow of bones. In blood-forming tissues the red corpuscles are nucleated, and they preserve their nuclei in the blood of frogs and other lower vertebrates; but in mammals they lose them and are set free in the blood as flattened, round, biconcave disks (oval in camels). Their red colour is due to the respiratory pigment, **hæmoglobin.**

White Corpuscles (Plate 7). Several types of white corpuscle called **leucocytes** (Gk., *leukos*, white; *kytos*, hollow) are normally present in blood. They are all nucleated cells, irregular in shape, which are capable of independent movement and the ingestion of harmful matter in the blood. They are formed principally in the spleen and the liver; when the body is attacked by disease-producing organisms they are formed in abnormally great numbers. They are probably all concerned to some extent with the protection of the body against bacteria (p. 215) or the absorption of poisonous substances.

3. The Circulation of Blood

Much of the anatomy of the blood-circulatory system had been discovered by early workers, who realized that the contained blood was in constant motion, though they differed in respect of the direction of this flow. Most observers were, however, influenced by the ideas of the Greek Galen (A.D. 130–200), who had held that the blood in vessels ebbs and flows towards and from the centre of the body.

By the sixteenth century we find a Spaniard, Miguel Serveto, or Servetus (1511–53), reaching out towards the idea of blood moving in a circular manner. Unfortunately, Servetus held strong religious views, and owing to differences of opinion between Calvin and himself, he was burnt at the stake before he had time to complete his researches. It was not till some seventy years later that an Englishman, William Harvey, demonstrated that the blood follows a closed circulation round the body.

William Harvey (1578–1657) (Plate 30). Towards the end of the sixteenth century William Harvey travelled as a young English student to Padua, Italy, to study under the direction of the great Italian anatomist Fabricius. A few years after his return Harvey was elected to a Fellowship of the Royal College of Physicians, and he later became Physician to King James I.

In 1628 Harvey published the results of his researches into the blood of animals. He referred to his examination of the heart and circulatory system in nearly forty different species of animals, and put forward his discovery that blood must continuously flow round the body in one direction only. Such an idea conflicted with the views of his teacher Fabricius, and with most contemporary workers, who followed the classical views of Galen.

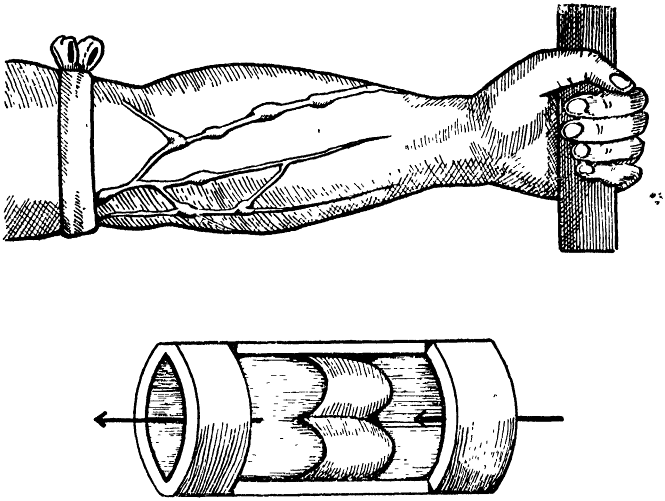

FIG. 51. THE VALVES IN VEINS

The upper figure, redrawn after Harvey, shows that the valves in the arm veins swell as the flow of blood is checked by a tight bandage between the veins and the heart. The lower diagram shows the arrangement of the 'watch-pocket' valves in veins.

Harvey reasoned that as one ventricle in the heart of a man holds two ounces of blood, and as that ventricle beats approximately seventy-two times a minute, at least 540 pounds of blood —*i.e.*, three times the weight of a heavy man—must pass through the heart every hour. Where could all this blood come from or go to unless there was a continuous and rapid circulation of blood round the body and through the heart? The ebb and flow theory was inadequate to explain this phenomenon.

Harvey was able to show that blood flows along the veins towards the heart and to demonstrate the significance of the valves in veins, which had been discovered, though wrongly interpreted, by his teacher Fabricius. The only important fact not noticed by Harvey was the existence of the blood capillaries which connect arteries and veins. Harvey's theory demanded the existence of such capillaries, but the inadequate methods

available in his age could not show their presence. They were not studied until the discovery of the microscope, when Malpighi (1628–94) noted the fine capillary vessels in the lung of a frog; van Leeuwenhoek (1632–1723) extended this work by observing the circulation of blood in the tails of tadpoles, through the thin capillary vessels which connect arteries and veins (pp. 205, 206).

4. The Functions of Blood

Blood circulating constantly round the body subserves several functions:

(i) *The Transport of Oxygen.* The transport of the respiratory gases, oxygen and carbon dioxide, is an important function of a circulatory system. Hæmoglobin is a **respiratory pigment** which has the power of combining with these gases. Thus, 100 millilitres of our blood will take up 19·0 millilitres of oxygen, while 100 millilitres of sea-water would absorb only 0·7 millilitres of oxygen.

The earthworm also possesses hæmoglobin, but some animals have other respiratory pigments. Snails, lobsters, and some other types have **hæmocyanin,** a pale blue fluid. Hæmoglobin and hæmocyanin are both proteins, combined with traces of iron and copper respectively. We therefore need small amounts of iron in our food. There is less than $\frac{1}{10}$ oz. of iron in the body, yet a shortage of iron is fairly common and results in the disease called anæmia.

(ii) *The Transport of Food.* Food which has been digested is absorbed by the blood and then carried to such cells as may require it. The chemicals are carried in a dissolved form in the blood plasma.

(iii) *The Transport of Waste Materials.* Many chemical substances, which are formed as the result of breaking-down (katabolic) changes in cells, are of no further use to the body and are therefore carried in the blood plasma to those points whence they can be excreted.

(iv) *The Transport of Chemical Regulators.* Much of the control of bodily functions is performed by certain chemicals called 'hormones,' which are carried in the blood plasma.

(iv) *Protection against Disease.* The white corpuscles can engulf bacteria and other harmful organisms; the blood plasma can carry chemicals which will neutralize or destroy bacteria.

(vi) *The Maintenance of an Even Temperature.* The blood conveys heat from any overheated part of the body to cooler parts, and thus maintains all parts of the body at a uniform temperature.

5. The Circulatory System and the Heart

The arrangement of the blood-vessels in animals depends largely on their method of respiration. In man respiration is effected by means of lungs and the circulatory system is so arranged that all the blood in the body passes through the capillaries in the lungs during its circulation.

In man veins bring blood from the various tissues in the body and join to form two large veins which enter the heart. One of these main veins, the **superior vena cava,** collects blood from the head region and arms; the other, the **inferior vena cava,** collects blood from the legs, kidneys, liver, and abdomen.

The blood gathered by the veins is passed on to the lungs by the pumping motion of the heart. The mammalian heart is a muscular organ containing four chambers through which the blood passes. Blood enters thin-walled chambers of the heart called **auricles** (L., *auricula*, little ear) which pass the blood on to thick-walled muscular **ventricles** (L., *venter*, belly). The whole organ expands and contracts rhythmically about seventy times each minute, thus maintaining a constant flow of blood round the body.

Blood from the venæ cavæ enters the right auricle of the heart and from there passes through a valve into the right ventricle; a valve between these chambers permits the flow of blood in one direction only.

From the right ventricle the blood is pumped along the **pulmonary artery** (L., *pulmo*, lung) into the lungs and is then returned to the heart along the **pulmonary vein,** which enters the heart at the left auricle. The left auricle passes the blood through a valve into the left ventricle, which pumps the blood back to the various organs of the body. The main artery which leaves the heart is called the **aorta**; this main vessel later divides into a large number of smaller arteries.

Every tissue in the body is supplied by a branch of an artery, which carries oxygen-bearing blood to it, and also by a branch of a vein, which carries blood containing carbon dioxide away from the tissues and back to the lungs, where it may be reoxy-

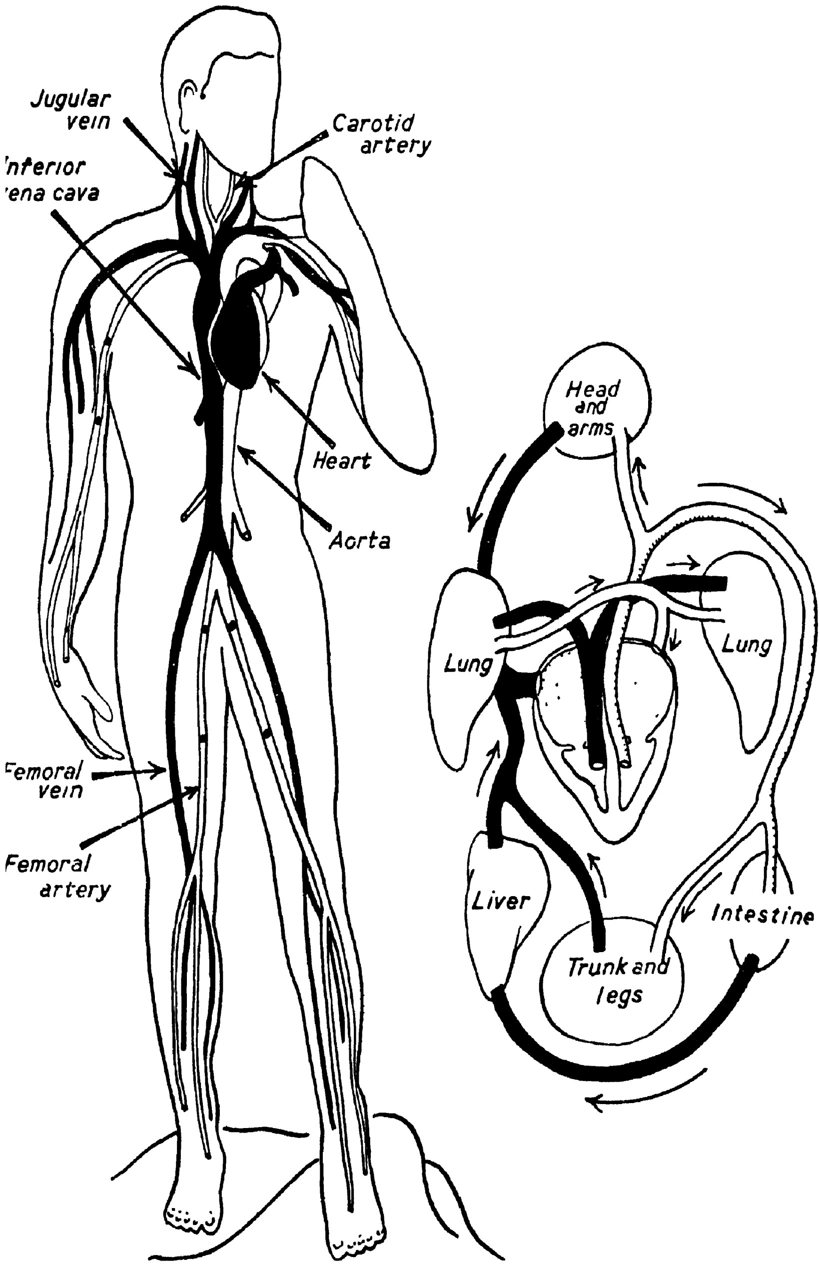

FIG. 52. THE BLOOD SYSTEM OF MAN

The positions of the heart and the main arteries and veins are shown, and the circular black spots on the arteries denote the position of the main 'pressure-points.' The smaller diagram shows the course of the blood round the body.

genated. Usually, therefore, veins carry blood containing carbon dioxide, while arteries usually bear oxygenated blood. It is better, however, to define **veins** as vessels bearing blood **to** the heart and **arteries** as vessels bearing blood **from** the heart, because the pulmonary artery carries 'venous' blood and the pulmonary vein bears 'arterial' blood.

When blood reaches the capillaries some of the fluid plasma called **lymph** (Gk., *lympha*, water) soaks through the capillary wall and actually bathes the cells of the body, carrying to them

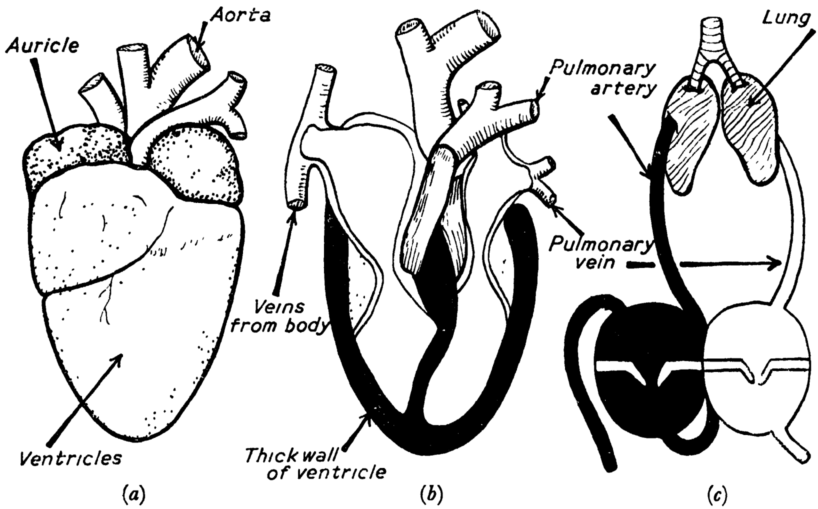

FIG. 53. CIRCULATION OF BLOOD THROUGH THE HEART

(*a*) A sheep's heart; (*b*) sheep's heart cut open to show arrangement of auricles, ventricles, and valves, the black shading representing the thick walls of the ventricles; (*c*) diagram showing the direction of blood-flow through the heart and the lungs.

food and oxygen. Lymph is collected later by fine vessels called lymphatic vessels, which carry the lymph back to the main circulatory system.

Blood-pressure. The average pressure of the blood in arteries and veins remains fairly constant in healthy animals, but local changes in the walls of the blood-vessels occur under certain conditions and cause local variations in blood-pressure. For example, after heavy muscular effort the blood-vessels supplying the muscles dilate and allow more blood to penetrate the muscles and carry away the waste products of respiration. The blood capillaries in the skin also dilate to permit increased heat-loss. Consequently our skin flushes after exertion.

After a heavy meal the blood-vessels of the digestive organs dilate and allow an increased flow of blood to the stomach and intestines.

A hot bath results in a dilation of the blood-vessels of the skin, which causes much blood to be withdrawn from the internal organs to the periphery of the body. It is clear, therefore, that exercise or hot baths, which withdraw blood from the digestive system, should not be taken too soon after a heavy meal, or too heavy a strain will be laid on the circulation.

The control of blood-pressure is exercised by the nervous system, which regulates the size of arteries. Violent emotion is generally accompanied by an increased tension of the arterial walls and a rise in blood-pressure. The blood-vessels of our faces are particularly sensitive to emotional change, and so we pale with fear or blush with embarrassment as the blood-vessels contract or dilate.

6. Wounds and Loss of Blood

Clotting and Wounds. When blood is exposed to the air it undergoes a series of chemical changes by which it **clots** and becomes solid. This clotting of blood is of the utmost importance in case of injury, for in this way a protective covering is formed at the wound and any further loss of blood is prevented.

When the wound is severe the pressure of the blood circulation forces blood through the wound before it can clot. First-aid in the case of injury attempts to arrest the flow of blood so that clotting can occur. In the case of cut veins a pad on the wound and a tight bandage on top will generally stop the flow of blood, but in the case of cut arteries other methods may be necessary. Arterial bleeding can be easily recognized by the very great flow of blood, which escapes in strong spurts. When arterial bleeding is severe an attempt should be made to compress the artery between the wound and the heart. It is therefore important to learn the so-called **pressure-points** where this can be done to check the flow of blood for a short time.

Normally arteries lie deeply seated and well protected by muscles and other tissues, but at some points the arteries pass fairly close to the surface and lie close to a bone, against which they can be compressed. For instance, the brachial artery, which supplies the arm and hand with blood, passes near the

humerus bone, especially at a point about half way down the upper part of the arm, as shown in Fig. 52. Pressure on this point will stop the flow of blood to the hand, as may be shown by the disappearance of the 'pulse' in the wrist, which is another pressure-point.

Blood Transfusion. Considerable loss of blood can cause death. In order to overcome this doctors have devised methods whereby some of the blood of healthy individuals can be transfused into the blood-system of the wounded patient.

This process is complicated by the fact that the blood of different individuals will not always mix safely. In many cases the red corpuscles contain different chemical compounds, which we may call A and B. There are thus four possibilities in the human species: the individual may have neither substance (group O), A or B substances, or both (group AB). The blood serum becomes adjusted to the presence of A or B substance in the blood, but if the blood of the patient contains a substance which is absent from the donor's blood, chemical reactions will occur which will be disastrous for the patient. Group AB can therefore receive blood from any individual, blood from A or B groups can only be transfused into individuals who possess A and B substances in their blood, while group O can give blood to all the three other groups of individuals, but receive blood from group O only.

SUMMARY

(1) In plants the transport of materials occurs in tubular cells, which are grouped together to form vascular bundles. This movement of materials occurs without the agency of any pumping organ.

(2) The tissues of most animals are bathed by the fluid called blood. This is contained in vessels which permit a circulation of blood round the body. The circulation is initiated and maintained by the action of the heart.

(3) Blood transports food, excretory products, oxygen, carbon dioxide, and chemical regulators, and protects the body against disease.

(4) Damage to blood-vessels is repaired by blood-clotting. In cases of serious injury severe loss of blood can be prevented by pressure and bandages.

SUGGESTIONS FOR HOME STUDY

(1) Why must blood circulate if it is to perform its functions adequately? Write an account of the discovery of blood circulation.

(2) Through what structures do materials move in plants (*a*) from the soil to the leaves, (*b*) from the leaves of a potato plant to the tubers?

CHAPTER XII

MOVEMENT AND SUPPORT

Children, you are very little,
And your bones are very brittle;
If you would grow great and stately,
You must try to walk sedately.

R. L. STEVENSON, *A Child's Garden of Verses*, "Good and Bad Children"

THE bodies of most animals and plants keep a rigid shape because they are supported by a framework of hard material, which forms the **skeleton** (Gk., *skeletos*, hard). Movement in most animals is effected by **muscles**, which are attached to the separate parts of the skeleton.

1. MUSCLES AND MOVEMENT

When you bend your arm you may notice that certain parts of the flesh harden. These are the muscles, which have become shorter, thicker, and more compressed as the arm is bent. This shortening of the muscles is the cause and not the result of the bending of the arm, since by their shortening the muscles have pulled the **bones** to which they are attached.

The human arm is raised or lowered by the action of two sets of muscles known as the **biceps** (L., *bis*, twice; *caput*, head) and the **triceps** (L., *tres*, three). If the biceps should shorten the triceps will lengthen, and the forearm will be raised. Contraction of the triceps and expansion of the biceps will lower the forearm.

It was not until the seventeenth century that muscles were known to exert their effects by an alteration in shape, not by a change in bulk, as had previously been believed. A worker called Swammerdam (p. 205) set up the apparatus shown in Fig. 54 and stimulated the nerve by a coil of wire; the muscle contracted, but the level of fluid in the tube did not alter.

Nerves control the activity of most muscles. The energy needed for the action of muscles is derived from the respiration of a chemical compound called **glycogen** (Gk., *glykys*, sweet) in the muscle cells.

The muscles of the body are either attached to bones, which

they move by acting as levers, or they are attached to other muscles. Muscles of the abdomen belong to this second type.

2. The Skeleton

The human skeleton is built of more than two hundred separate **bones**, most of which move freely and are hinged on each other at **joints.**

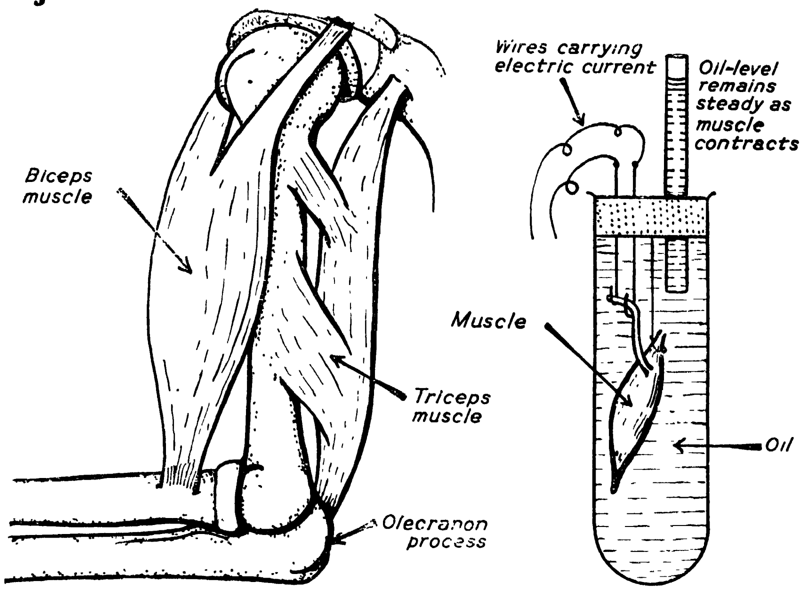

Fig. 54. The Action of Muscles

The left-hand figure shows the attachment of the biceps and triceps muscles of a left arm. The right-hand figure shows a modified version of Swammerdám's experiment indicating that contraction of a muscle is *not* accompanied by any change in volume. (See also Plate 19.)

The **backbone,** or spine, forms the foundation of our skeleton. It is formed of thirty-three bones called **vertebræ** (L., *vertebra*, joint), of which the lowest nine are fused together. The other vertebræ vary in shape according to the functions which they perform. Those in the abdominal region (**lumbar** vertebræ) have large transverse processes which protect the delicate internal organs and provide attachment for the back muscles. The **thoracic** vertebræ in the chest region have projections for **rib** attachments also, while the first two **cervical** (L., *cervix*, neck), or neck, vertebræ are so constructed that they allow the head to turn or nod.

Nodding of the head is effected by the **skull** rocking on the first or **atlas** (L., *Atlas*, a Titan) vertebra; the head turns by twisting the skull and atlas vertebra on the second, or **axis** (L., *axis*, axle), vertebra. This latter has a long peg which passes forward through a hole in the atlas.

The skull is constructed of many bones, which dovetail together to form a case which encloses the brain. The rest of the central

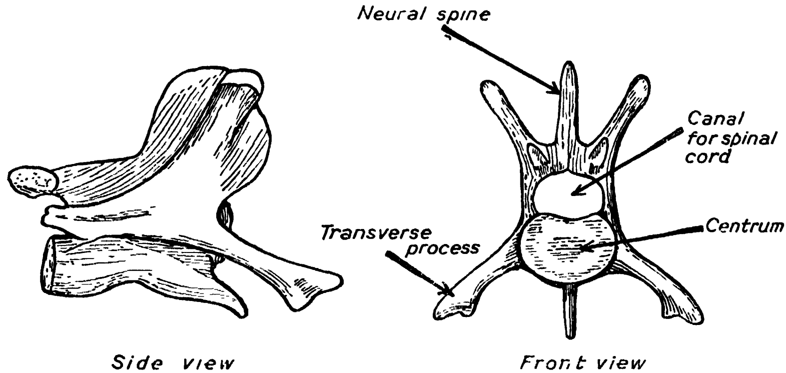

FIG. 56. SECOND LUMBAR VERTEBRA OF A RABBIT

nervous system, the spinal cord, lies in the backbone along a tube which passes through the vertebræ.

The skull and backbone together form the **axial** skeleton, which is fairly rigid. The **limbs** and **limb-girdles,** which are concerned with active movement, form the **appendicular** (L., *ad*, to; *pendere*, to hang), or hanging, skeleton, so called because of its flexibility.

The fore-limb, or arm, of man consists of three main bones, the **humerus** (L., *humerus*, shoulder), **radius** (L., *radius*, ray), and **ulna** (L., *ulna*, elbow). These last two bones cross over one another as the hand is turned. The bones of the wrist are called **carpals** (L., *carpus*, wrist); those of the hand are named **metacarpals** and **digits.**

The hind-limb, or **leg,** is constructed on a very similar plan. One main bone, the **femur** (L., *femur*, thigh), is hinged to the hip-girdle. A pair of bones, the **tibia** (L., *tibia*, flute) and **fibula** (L., *fibula*, buckle), **articulate** (L., *articulus*, joint) with the femur at one end and the ankle bones, the **tarsals** (Gk., *tarsos*, sole), at the other. The feet, like the hands, are built of many bones, which are called **metatarsals** and **phalanges.**

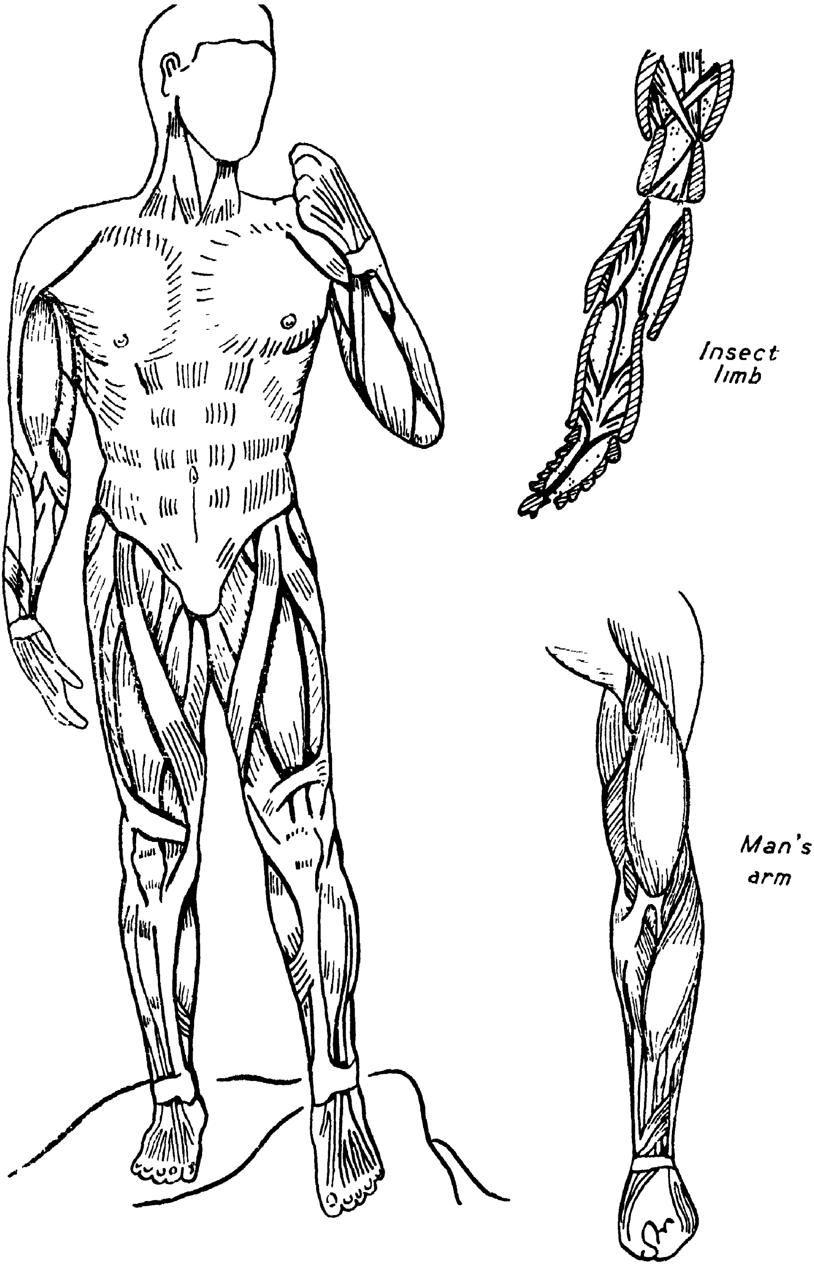

FIG. 55. SUPERFICIAL MUSCLES IN THE BODY OF A MAN

The smaller figures show the differences between the muscle attachments of an invertebrate and a vertebrate limb. The upper and lower figures at the right are redrawn after Hogben and Thompson respectively.

Our arms swing from a shoulder, or **pectoral** girdle, which is built of two collar-bones, or **clavicles** (L., *clavis*, key), and two shoulder-blades, or **scapulas.** Our legs articulate with a hip-girdle, or **pelvic** girdle, which is built of six bones firmly fused to each other and to the backbone.

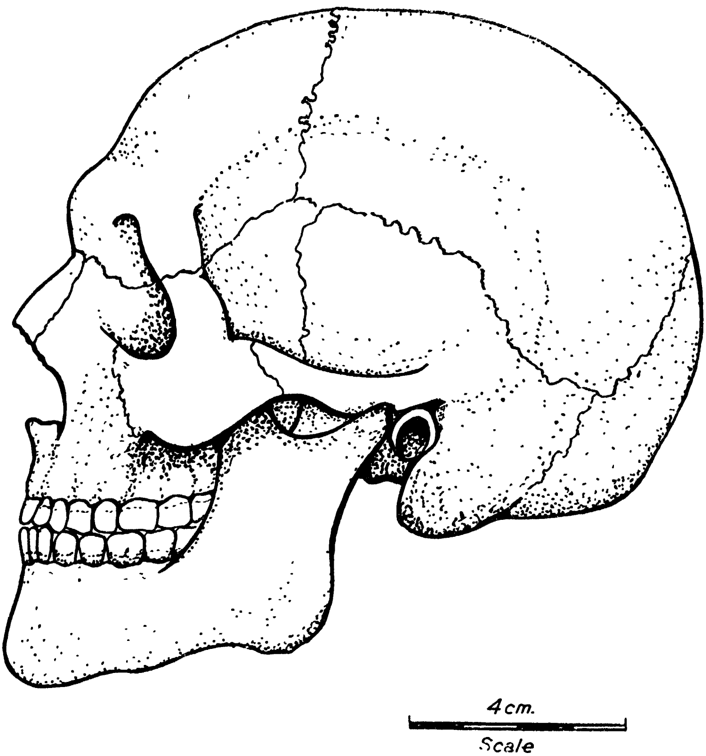

FIG. 57. HUMAN SKULL VIEWED FROM THE LEFT SIDE

Ribs, which enclose the pleural cavity, are hinged on behind to vertebræ. The upper ten ribs on either side are attached in front to a **sternum,** or breastbone. The remaining two pairs of ribs are unattached in front and are therefore known as the floating ribs. Contrary to popular belief, men and women have the same number of ribs.

3. JOINTS, CARTILAGE, AND BONE

If you look at the way in which bones are hinged together you will see that the limb-bones articulate by means of a 'ball-socket'

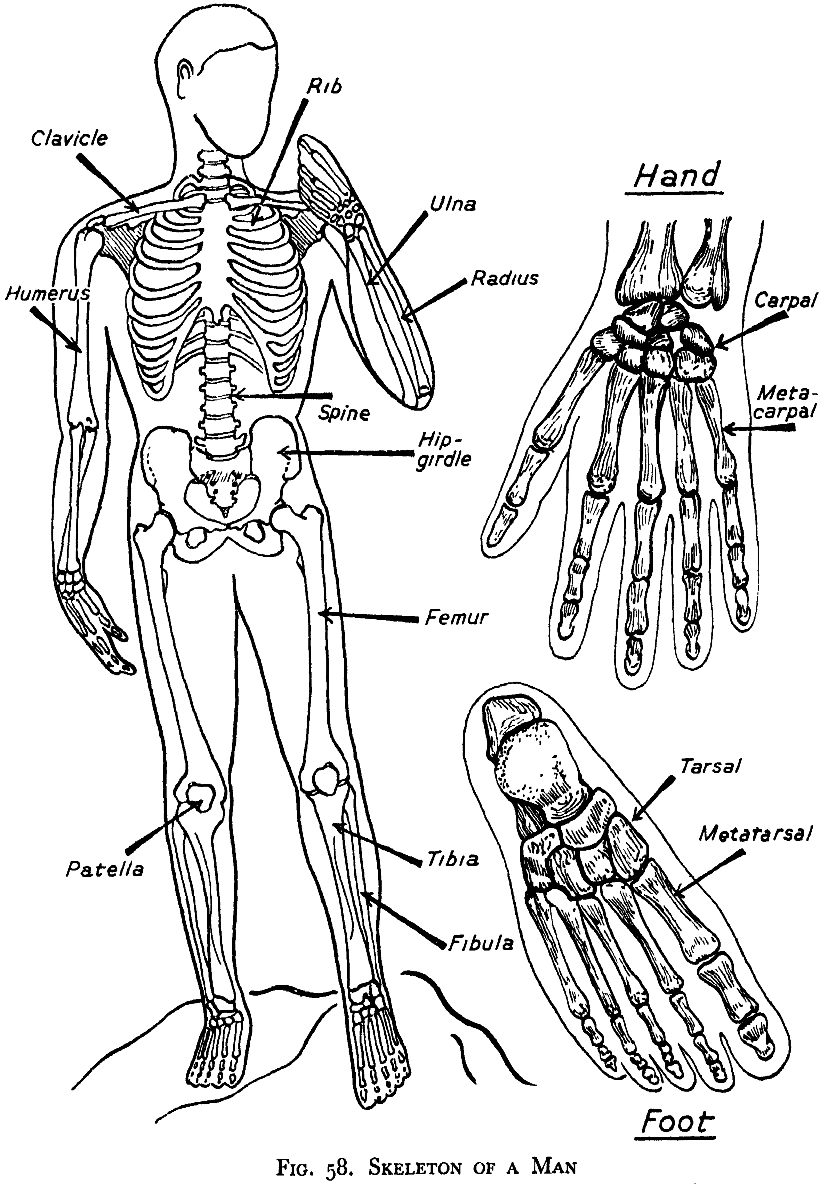

FIG. 58. SKELETON OF A MAN

On the right are shown enlarged views of the bones in the hand and the foot. See also Plates 7 and 8.

type of joint. The end of one bone is rounded and fits into a socket at the end of another bone, which enables it to move freely.

The bones are held in position at a joint by **ligaments** (L., *ligamentum*, bandage), or **tendons**, which form tough, fibrous connexions. Muscles are also attached to bones by means of similar tendons. Meat is composed of muscle, while the tough, stringy sinews represent tendons.

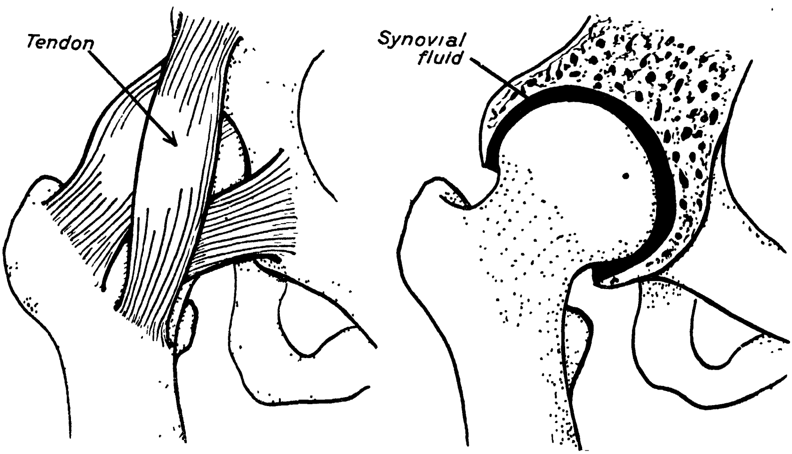

FIG. 59. HIP-JOINT, SHOWING THE TENDONS AND THE BALL-AND-SOCKET TYPE OF ARTICULATION

In the right-hand figure the tendons have been removed and a portion of the hip-girdle has been cut away.

Where two bones meet at a joint their rubbing surfaces are covered by a thin layer of **cartilage,** or gristle, a smooth, slimy elastic substance, which lessens friction at the joints and acts as a shock-absorber to prevent the more brittle bones from hitting each other and breaking. As the cartilage wears away it becomes the **synovial fluid,** which is contained in bags of connective tissue and serves to lubricate the joints.

Bone is composed of living cells which deposit two substances called **collagen** (Gk., *kolla*, glue; *genos*, offspring) and **calcium phosphate** in concentric layers round blood-vessels. Limb-bones are hollow and contain a fatty material called **marrow** in the centre.

The softer parts of bone are generally strengthened by a fine lattice-work of bony structures called **trabeculæ**. The disposition of these structures provides a very striking illustration

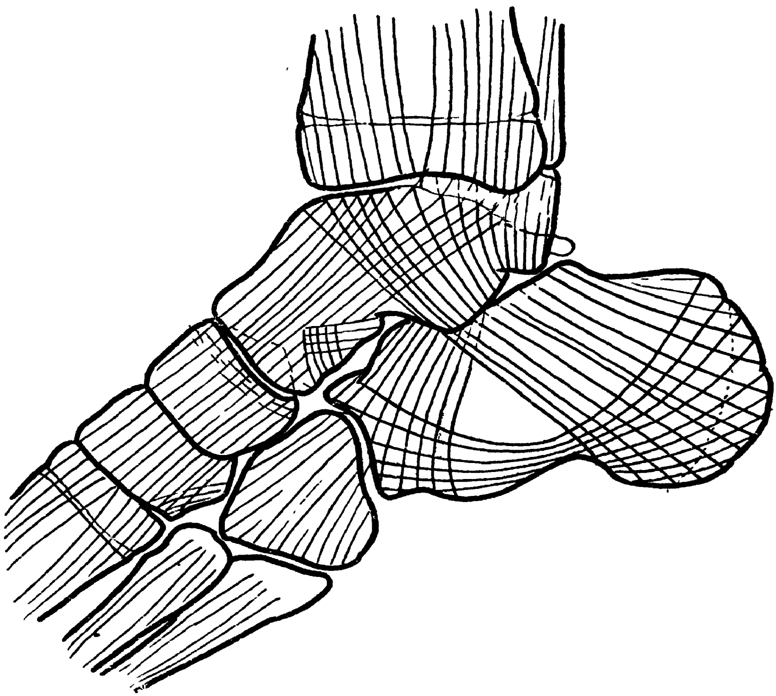

Fig. 60. Diagram of Some of the Stress-lines in the Human Heel

This figure, redrawn and modified from Meyer, should be compared with Plate 8.

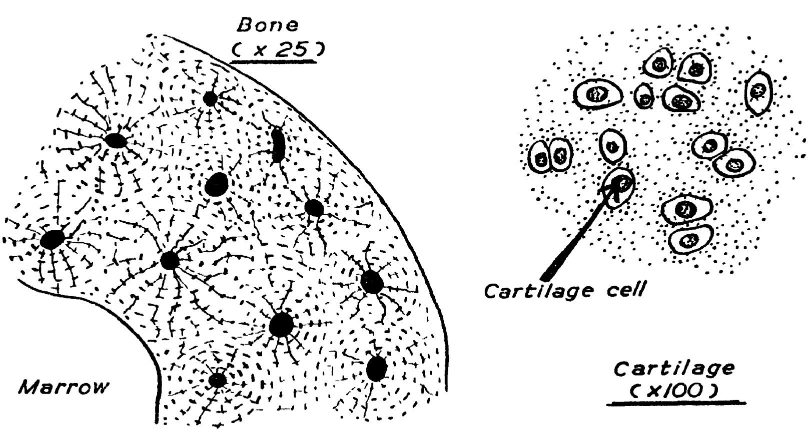

Fig. 61. Minute Anatomy of Bone and Cartilage compared

The portion of bone illustrated is a transverse section through a small sector of an arm or leg bone. The approximate scale of magnification is shown on the figure.

of the close relationship between structure and function in living things; indeed, one may be said to determine the other. The trabeculæ take up positions along the lines of stress and strain to which the bone is subjected (see and compare Fig. 60 and Plate 8).

Cartilage is built up mainly from the substance collagen,[1] and as this is more pliable than calcium phosphate, cartilage forms suitable pads between bones. Our skeletons contain less collagen as we grow old, and consequently the bones become brittle and easily broken, while we appear to shrink in length, since the pads of cartilage between the vertebræ disappear.

The growth in length of long bones—*e.g.*, those of the limbs, hands, and feet—involves the multiplication of bone and cartilage. Each long bone consists of a bony shaft, the diaphysis capped at either end by bony caps called epiphyses. A small pad of cartilage separates each epiphysis from its diaphysis. As growth proceeds the end of the diaphysis forms bony material which encroaches on the epiphysial cartilage; this in turn multiplies at a corresponding rate, and so the bone is lengthened. Growth takes place mainly at one end of each bone and slackens as maturity is reached. In time the pads of cartilage between diaphyses and epiphyses become converted to bone, and the elongation of the bone is complete.

If you burn a bone the collagen is transformed into other substances, and the bone will become very brittle. Conversely, if you place a bone in hydrochloric acid the calcium phosphate dissolves, leaving the bone soft and pliable.

4. Types of Skeletons

Among the lower animals we find a variety of skeletons. Some, like the shells of mussels, snails, and other molluscs, protect the animal but impede its movement; others, like the skeletons of some sponges, form a rigid internal framework for the body. Among invertebrates it is only the insects, spiders, crustaceans, and other arthropods that possess a freely jointed skeleton which serves for movement, protection, and support.

When we compare the skeleton of an arthropod, say a housefly, with that of a vertebrate one difference is clear. The arthro-

[1] Collagen, if it should be boiled in water for some time, will become converted to gelatin.

pod's skeleton is external, not internal, and the muscles are attached to the inner surfaces of the skeleton. The latter consists of a number of separate plates of a substance called **chitin.**

Such an arrangement has both an advantage and a disadvantage, in that it protects the body most effectively, but it restricts growth. For the **exoskeleton,** or outer skeleton, of the arthropod is not elastic and must be shed at intervals, growth proceeding between successive moults each of which is known as an **ecdysis.** If you keep water-fleas or shrimps, for example, in an aquarium you will find their cast-off skeletons from time to time. During the short periods that it is without a skeleton an arthropod moves with difficulty and is very vulnerable.

The vertebrates have **endoskeletons,** or inner skeletons, formed of bone and cartilage. There is a surprising uniformity of type among these skeletons of vertebrates. The skulls, backbones, limbs, and limb-girdles are all built on the same fundamental plan. If you examine the skulls of a dog and a man you will see that they are built of the same number of bones, which are similar, except in their sizes and proportions. Vertebræ also show great similarities in the various types, but there is a certain degree of diversity among the limbs and limb-girdles.

Fins for swimming, wings for flying, and limbs for running are modified according to the purpose they serve, yet in spite of this specialization there is an underlying unity of plan (Fig. 139). We may construct a 'ground-plan' of the vertebrate limb, and if it be compared with the variety of forms it may assume we find that our basic plan is present in all types, though in some it has become reduced, while in others it is supplemented by the addition of extra bones.

5. Support in Plants

Young leaves and young stems owe their rigidity to the phenomenon of osmosis, whereby water is taken into the cells. In this way the latter become distended as they are filled with protoplasm, cell-sap, and water, and so they remain fairly rigid.

When water evaporates from the surface of a young plant more rapidly than it can be taken in the cells lose their state of turgor and the plant droops or wilts. Young transplanted seedlings will wilt if they are exposed to bright sunshine before their roots have recovered from the damage due to transplanting.

Most of the larger herbs, shrubs, and trees are rigid because they contain internal skeletons formed by the thickening of certain cell-walls, especially those of the water-conducting system.

SUMMARY

(1) Many animals are built on a solid framework, the skeleton, which protects the delicate internal organs and assists in movement.

(2) The skeletons of invertebrates are generally external; those of vertebrates are internal.

(3) Skeletons of vertebrates are formed of many bones and pads of cartilage.

(4) Muscles attached to bones move them, like levers.

(5) The skeletons of vertebrates are built on a common plan, modified in the different types.

(6) Plants remain erect because of thickening of the walls of certain cells or the turgor of the contents of the cell.

SUGGESTIONS FOR HOME STUDY

(1) Compare the skeletons of a man, an insect, and a plant.

(2) Explain the structure and action of a hip-joint.

CHAPTER XIII

EXCRETION: THE REMOVAL OF WASTE

But neither pills nor laxatives I like,
They only serve to make the well-man sick.

. DRYDEN, *The Cock and the Fox*

THE food materials which animals eat are transformed in the body by means of chemical reactions. During these and other transformations of material in the body a certain amount of wastage ensues, and the waste chemical substances are removed by a process called **excretion** (L., *ex*, out; *cernere*, to sift).

1. UNWANTED FOOD: THE REMOVAL OF FÆCES

A proportion of the food which animals eat is not absorbed by the body; consequently this waste material, having passed through the digestive system without change, leaves the body through the **anus.**

Waste materials collect in the **rectum** (L., *rectus*, straight), or **bowels,** where, if they are allowed to accumulate, they may give rise to chemical substances which act as mild poisons on the body. The importance of emptying the bowels at frequent (daily or more often) intervals is therefore clear.

The materials which pass from the bowels through the anus to the exterior are collectively known as the **fæces** (L., *fæces*, dregs). It is important to realize that this excreted material has never formed part of the body but represents only the indigestible substances in the food.

Many of the diets consumed by civilized people, together with their mode of life, lead sometimes to a temporary condition called **constipation,** which occurs if the bowels are not emptied every day. The mild self-poisoning so induced may lead to tiredness and depression; prolonged constipation may even become dangerous.

Chemical substances called laxatives are sold for the relief of constipation, but their regular use is not wise. Exercise, a healthy diet, and, above all, regular habits in emptying the bowels, are greatly to be preferred.

2. The Kidneys

A great deal of waste material is formed in the animal body as a result of respiration and of the other chemical reactions which together constitute metabolism.

To take a particular instance, movement by means of muscular

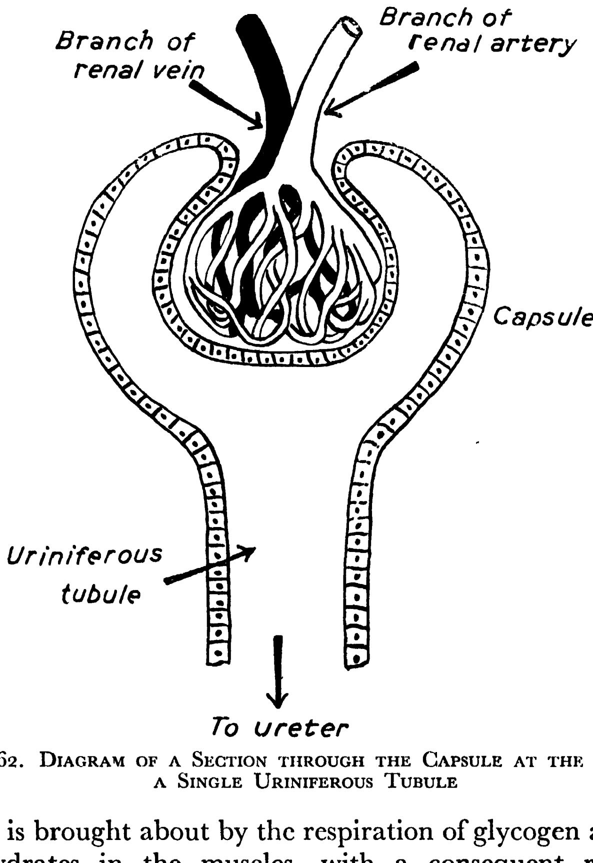

FIG. 62. DIAGRAM OF A SECTION THROUGH THE CAPSULE AT THE END OF A SINGLE URINIFEROUS TUBULE

activity is brought about by the respiration of glycogen and other carbohydrates in the muscles, with a consequent release of energy for movement. Much of an animal's food consists of protein material, and it therefore follows that a certain amount of waste nitrogen material must be left after the conversion of proteins to carbohydrates. This waste nitrogen collects as relatively simple nitrogen compounds, such as **urea** ($CO(NH_2)_2$), and is later excreted in a fluid, the **urine,** which contains other salts in addition to urea. Waste matter that is rich in nitrogen is called 'nitrogenous waste.'

The task of collecting urine is performed in vertebrates by a pair of organs called **kidneys.** The renal (L., *ren*, kidney) arteries bring blood to the kidneys, the artery dividing there into a large number of small capillaries. Each capillary splits up into a network of fine vessels, which is contained in a capsule (see Fig. 62). The walls of this capsule are thin, and the waste chemical substances can soak through the capsule walls into a collecting tubule, the **uriniferous tubule.** Each kidney contains thousands of such capsules and tubules. All the uriniferous tubules meet and form a single ureter from each kidney.

The ureters pass the urine into a sac, the **bladder,** in which the urine is stored. It is then excreted periodically to the exterior. In cold weather the volume of urine is great, but in hot weather much of the excess water and some of the nitrogenous waste is removed by sweat.

3. Sweat

Excretion in mammals also occurs by the activity of **sweat-glands.** These glands are situated in the skin and open by small pores on its surface. Each gland is well supplied by blood-vessels. Sweat glands normally excrete sweat constantly, the sweat evaporating from the surface of the skin.

Sweat is mainly water, but it does also contain about 2 per cent. of nitrogenous waste matter, which is thereby removed from the body.

Sweat also contains a fairly large amount of common salt, and excessive sweating removes too much of this compound from the body. Miners and stokers, who take violent exercise in a hot atmosphere, used to suffer from a mysterious cramp, which was subsequently found to be caused by the drain of salt from their bodies in their sweat. The remedy is very simple. Such workers to-day drink water and eat salt.

Evaporation lowers the temperature, and so the evaporation of sweat helps to regulate our temperature; consequently, the sweat-glands are especially active during periods of great exercise.

Many fur-bearing animals have no sweat-glands, and must therefore cool themselves by evaporation from the surface of the lungs, mouth, and tongue. A dog has only a few sweat-glands, which are on the soles of his feet, so when a dog is hot his tongue hangs out and he pants furiously.

Evaporation from a surface is directly influenced by the moisture in the atmosphere; a dry atmosphere will encourage evaporation, while a moist one will not. A temperature of 100° F. in the shade is therefore extremely oppressive in England, where the air is never dry, but in Australia, where the air is dry, the same temperature would not prevent violent exercise.

Heat regulation is performed by birds and mammals, which maintain their bodies at even temperatures. The feathers and

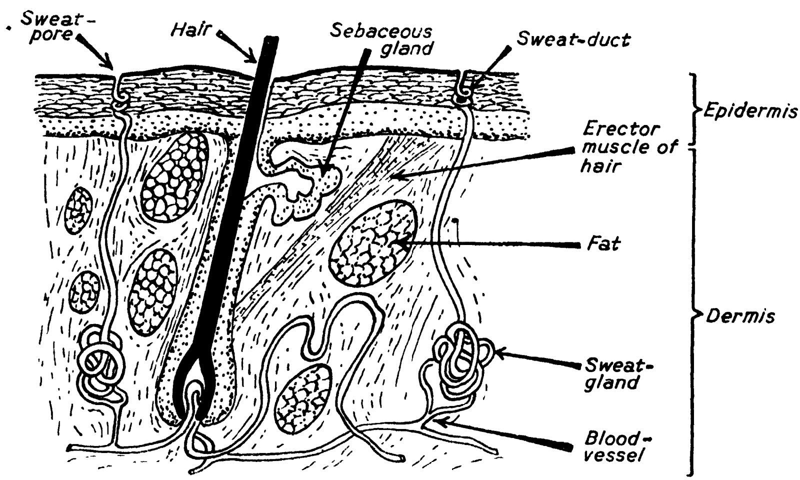

FIG. 63. SECTION THROUGH HUMAN SKIN

hair prevent heat-loss in cold weather, while cooling by evaporation prevents over-heating in hot weather. Evaporation takes place from the inner surface of the lungs and large air-sacs in birds, which have no sweat-glands. Lower animals cannot control their body-temperature, which varies with the temperatures of their surroundings, and are therefore hampered in their activities by very high or very low temperatures.

SUMMARY

(1) Undigested food matter is removed through the anus in the form of fæces.

(2) Many digested foodstuffs undergo great changes in the body. The conversion of chemicals in the body liberates considerable amounts of waste materials, in particular the element nitrogen, in the form of nitrogenous compounds.

(3) The kidneys and sweat-glands remove nitrogenous waste from the body.

(4) Sweat also cools the body by evaporating from the skin.

SUGGESTIONS FOR HOME STUDY

(1) Compare the lungs, kidneys, and skin as organs of excretion.

(2) How does (*a*) exercise, (*b*) hot or cold weather, (*c*) the moisture in the atmosphere, affect excretion?

CHAPTER XIV

THE NERVOUS SYSTEM

Thought, he is inclined to hold, is still secreted by the brain.

T. CARLYLE, "Signs of the Times" in *Critical and Miscellaneous Essays*

WHEN we move away from a fire because it is too warm a number of organs in our body are involved. First the stimulus of heat is received by **heat-receptors** in our skin. Receptors are cells, or groups of cells, which are sensitive to a particular stimulus; ears, eyes, touch-receptors in the skin, taste-buds in the tongue, all receive impulses from the outside world.

The 'message' received by the heat-receptor is transmitted by **nerves** to muscles, which allow us to move. The muscle is called an **effector,** and the rôle of the nervous system is to connect receptors to effectors, so that animals can respond to events in the outside world.

1. THE NERVE-MUSCLE PREPARATION

The contraction of a muscle is generally controlled by a nerve, and its contraction is a response to some impulse transmitted by the nerve to the muscle. An experiment known as a nerve-muscle preparation can be used to show the action of a nerve on a muscle. In this experiment the nerve leading to a muscle is stimulated by electrical means, and the subsequent contraction of the muscle is recorded.

For a simple demonstration it is convenient to use the **gastrocnemius,** or 'calf' muscle, of the frog's leg, together with the sciatic nerve which supplied it. The muscle which is attached to a small piece of the femur is removed, as soon as possible after death, from a frog which has been killed by a cut through the backbone in the neck region. The accompanying figure shows the arrangement of a simple nerve-muscle preparation.

As an electric current passes between the electrodes *A* and *B* (Fig. 64) a nerve impulse is set up which stimulates the muscle to contract, so moving the lever and recording the movement on the drum. It is therefore clear that the stimulation of a nerve affects the activity of that muscle which it supplies.

By using more complicated modifications of this experiment, physiologists have learnt many facts about the nature of the nerve impulse. For instance, one can stimulate the nerve at several points and, by observing the different lapses of time between stimulation and response, calculate the speed of the

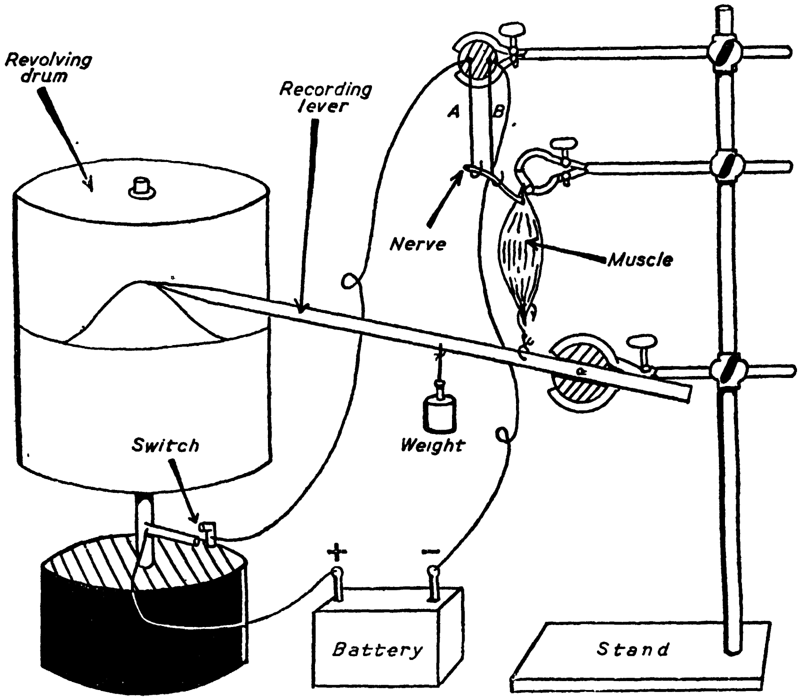

FIG. 64. MUSCLE-NERVE PREPARATION
A muscle, freshly removed from a 'pithed' frog, is mounted in such a way that it may be stimulated to contract. Since it is attached to a lever, made from a wooden spill, its contraction is recorded on the moving smoked drum.

nerve impulse. In man this speed is about two hundred miles per hour, while in the frog it is little more than sixty miles per hour.

Experiments have shown that, although an electric current will set up a nerve impulse, the impulse which travels along a nerve is, in fact, predominantly a chemical one. Nerves do not, like metal wires, possess the passive rôles of conductors, but themselves set up electric potentials when they are stimulated. There is therefore no constant fall in potential along a nerve as there is when an electric current passes along a wire, but rather

a succession of waves, or impulses, of chemical reactions, and therefore of electric potentials.

2. The Anatomy of Nerves

A cross-section through a single nerve shows it to consist of a bundle of fibres, which are insulated from one another and are

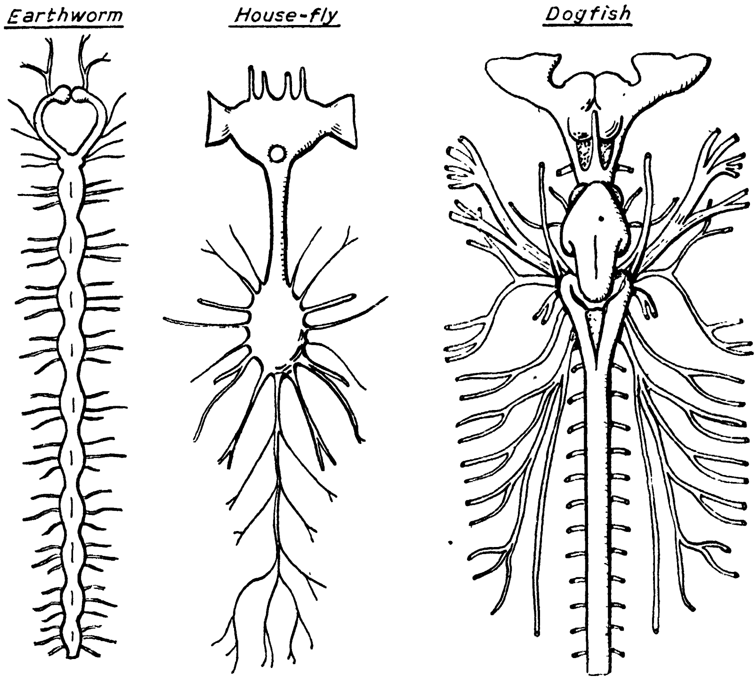

Fig. 65. Central Nervous Systems of an Earthworm, a House-fly, and a Dogfish

In each case the nervous system is viewed from above. The systems of the fly and the earthworm have been enlarged for ease in comparison, and in that of the dogfish the spinal cord and nerves of the hinder part of the body have been omitted. Note the greater concentration of nervous tissue to form the brains of the higher types.

packed together in a manner not unlike the many separate wires of an Atlantic telephone cable. A single fibre is called a **neurone** (Gk., *neuron*, nerve), or nerve-cell (see Fig. 19); a nerve is a composite structure, often containing neurones which control separate activities.

A typical neurone has the form of a long fibre, terminating at one end in a branching, nucleated mass of protoplasm, the **cell-body,** and at the other end in thin branches of protoplasm,

the **dendrites** (Gk., *dendron*, tree). Each fibre, or **axon** (Gk., *axon*, axis), is surrounded by a thin insulating sheath, and often by a thicker sheath also, which is composed of fat and other materials. In man a neurone may be as much as a yard in length, yet less than one-hundredth of a millimetre in thickness.

In the simpler animals, as, for instance, the sea-anemones, many interlocking neurones form a nerve-net, by which the

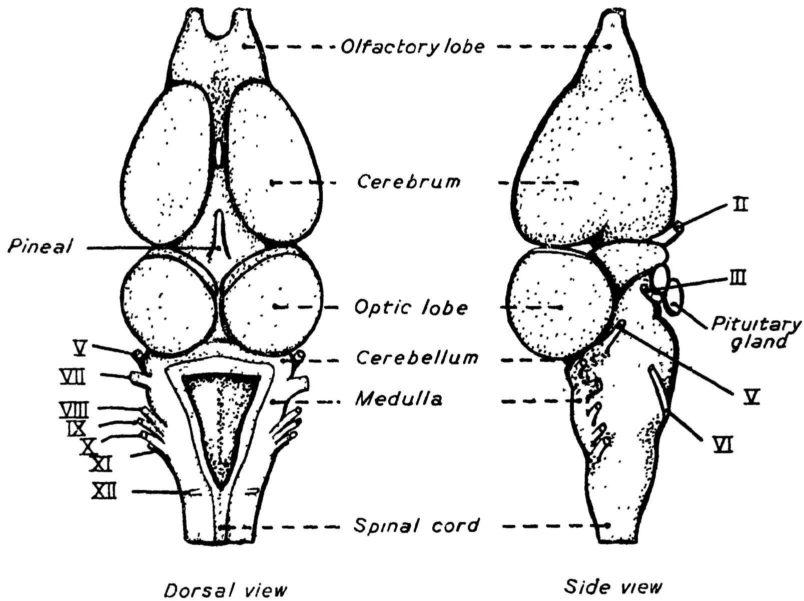

FIG. 66. BRAIN OF A FROG VIEWED FROM ABOVE AND FROM THE RIGHT SIDE

The Roman numerals denote the points at which various cranial (head) nerves leave the brain. This figure is drawn from a specimen and is magnified five times.

various responses of the body are co-ordinated. In the higher forms many of the nerve-cells are concentrated to form a **central** nervous system, which in man consists of the **brain** and the **spinal cord.** The remaining nerves then form what is known as the **peripheral** nervous system.

The concentration of nervous tissue to form a brain allows more elaborate behaviour to occur. The earthworm is capable only of simple responses. The fly, together with other arthropods, is able to respond to more complex situations. Vertebrates possess the ability to learn to a much greater degree than do invertebrates. A glance at Figs. 65, 66, and 68 will show you that the brain becomes proportionately more developed as we

pass from lower to higher animals. The earthworm has no true brain, but merely a series of tiny local 'brains' in each segment of its body. The house-fly has a brain in its head and another 'brain' in its thorax to control the movements of its wings and legs.

3. The Reflex Arc

The nervous system serves to control the responses of an animal to its surroundings, and so to enable the animal to adjust itself to favourable or unfavourable events. Sometimes a simple stimulus may evoke a complicated series of responses, as when, for example, the noise of a school bell will cause a boy to leave his breakfast, seize his books, and run to school. Before we can consider the relation of the nervous system to such complex behaviour we must consider the simplest form of response to a stimulus.

A single fixed response to a single stimulus is called a **reflex action** (L., *reflexus*, from *reflectere*, to turn back), and the path of the nerve impulses involved is termed the **reflex arc.** The 'knee-jerk' response (see Fig. 67) is a simple reflex action which is easily demonstrated in man. If you sit with your legs crossed and then sharply rap the upper leg just below the knee the leg will give a sudden kick, although no deliberate action is involved.

Two experiments on a frog will help to explain this behaviour. A frog is killed by a cut which severs the spinal cord in the neck region and is then placed so that the toes of one leg dip into a beaker containing water warmed to about 40° C. Although the frog is dead, he withdraws his leg from the water. If, however, the spinal cord has previously been destroyed by the passing of a wire down the centre of the backbone before the leg is dipped in water no response will be obtained. Such experiments suggest that the nerve impulses pass along nerves from the toes to the spinal cord, and then back along nerves to the muscles of the leg.

And so we see that one function of the spinal cord is to control local reflex actions like those described above. The spinal cord also conveys nervous impulses from the rest of the body to the brain and from the brain to the rest of the body.

4. The Brain

The knee-jerk reflex and the reflexes of the frog's leg involve only the spinal cord and the nerves leading to the leg but in most

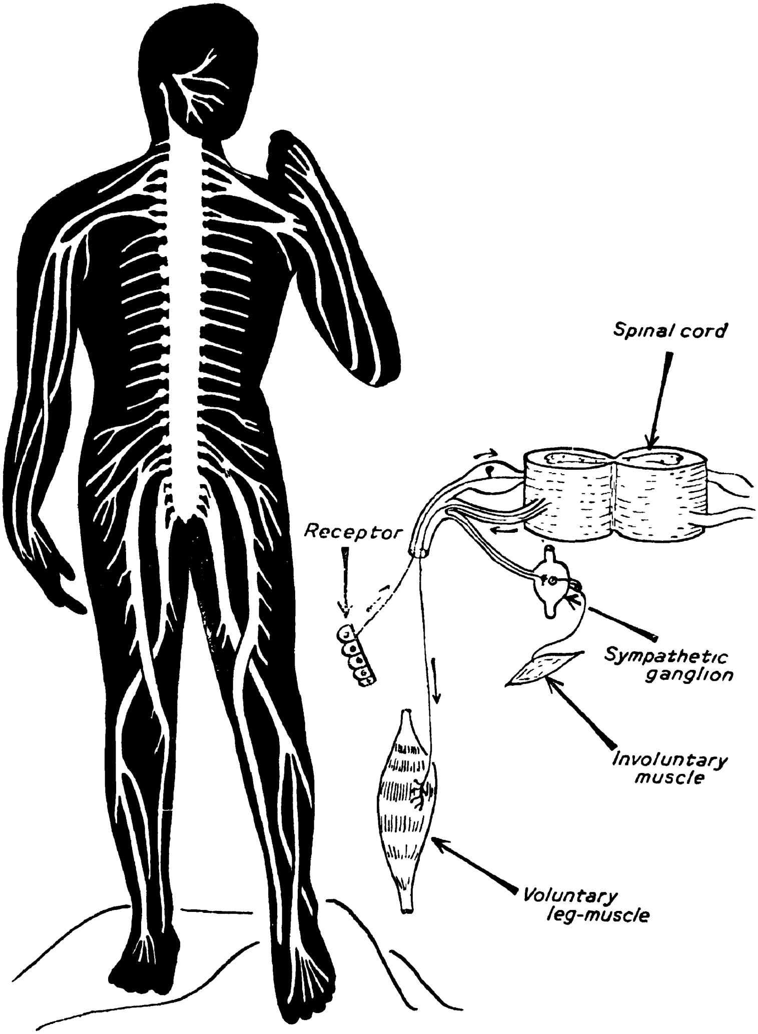

FIG. 67. DIAGRAM TO SHOW THE NERVOUS SYSTEM OF MAN
In this diagram the brain, the sympathetic system, and the small nerves have been omitted, and only the main nerves and the spinal cord are shown. The diagram on the right shows the course of the nerve impulse involved in the 'knee-jerk' reflex, and also the relationship which an involuntary muscle and a ganglion of the sympathetic system bear to the spinal cord.

of our actions the brain is also involved in the control of our conscious behaviour.

The brain relates the various activities of the body, such as hearing, seeing, moving, and eating, to one another and allows us to select the appropriate response to any stimulus. Simple

reflex actions take place almost instantaneously, and any given stimulus should always elicit the same response, but in actions which involve the brain a certain amount of choice of response, based on past experience, is possible.

The spinal cord may be compared, then, to a local automatic telephone exchange, and the brain to a central telephone exchange in which the operator chooses which subscribers should talk with

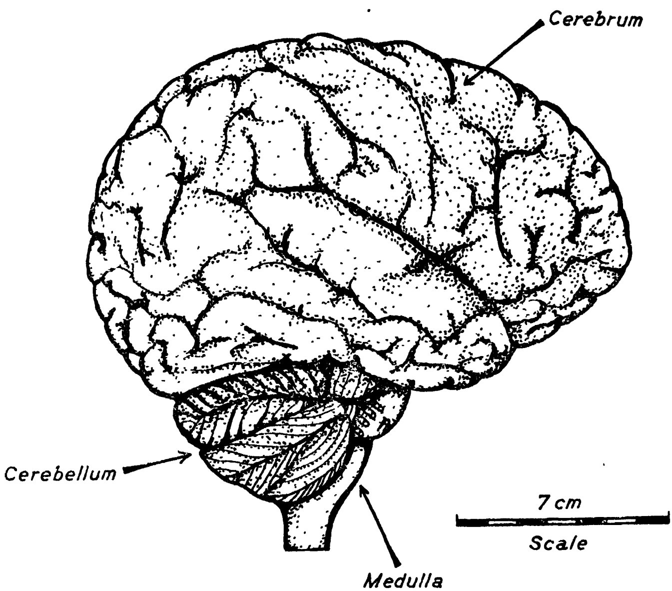

FIG. 68. THE HUMAN BRAIN VIEWED FROM THE RIGHT SIDE

one another. Like most generalizations and comparisons, this analogy has its faults, but it illustrates the fixed, automatic nature of a **simple reflex,** in contrast to the so-called **conditioned reflexes,** which arise by experience and involve certain regions of the brain. The brain has particular regions which are concerned with particular activities. If these regions are damaged some of the powers of response may be destroyed.

As we compare the brains of worms, insects, fishes, frogs, and men we find that the more advanced animals have proportionately larger brains. Man's brain differs from that of the frog in the great increase in size of the **cerebral hemispheres.** These regions are concerned with the association of various activities, and it is therefore not surprising that our power of learning (*i.e.*,

the establishment of conditioned reflexes) is greatly in advance of that of the frog.

Let us discover what is meant by a conditioned reflex by considering the work of a Russian, Professor Pavlov (1849–1936), who performed many interesting experiments on dogs.

Pavlov's experiments are fundamentally simple. Let us suppose that a hungry dog is offered a plate of food. His mouth

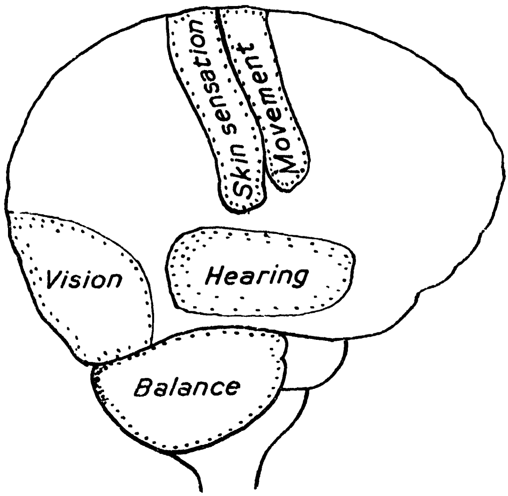

FIG. 69. DIAGRAM OF HUMAN BRAIN, SHOWING AREAS WHICH ARE BELIEVED TO BE CONCERNED WITH CERTAIN ACTIVITIES OF THE BODY
Compare this figure with Fig. 68.

will water because saliva will be produced by a simple reflex, which is a purely automatic and unconscious response. Pavlov's experiments consisted in producing some other stimulus, say a bell or a buzzer, together with the food each time that it was presented to the dog. After a number of such occasions the buzzer was sounded alone, without any food present, and the dog's mouth watered. So a **conditioned** reflex, that of associating food with the sound of a buzzer, had been established.

The conditioned reflex is the basis of learning. When a baby looks at a dog and says "bow-wow" it is because a conditioned reflex associating these two has been established previously in the baby's brain. In contrast, however, if you should shine a bright light suddenly in a baby's face his eyes would blink, as the result of a simple reflex. In this case also the brain is involved, but this response is an inherited one, not based on previous experience.

5. Receptors

The structure of the **eye** is, optically considered, not unlike that of a camera. In both the light rays pass through a **lens** (L., *lens*, lentil), which focuses them on a light-sensitive region, which in the case of the eye is called the **retina** (L., *rete*, net). The amount of light which enters the eye may be regulated by

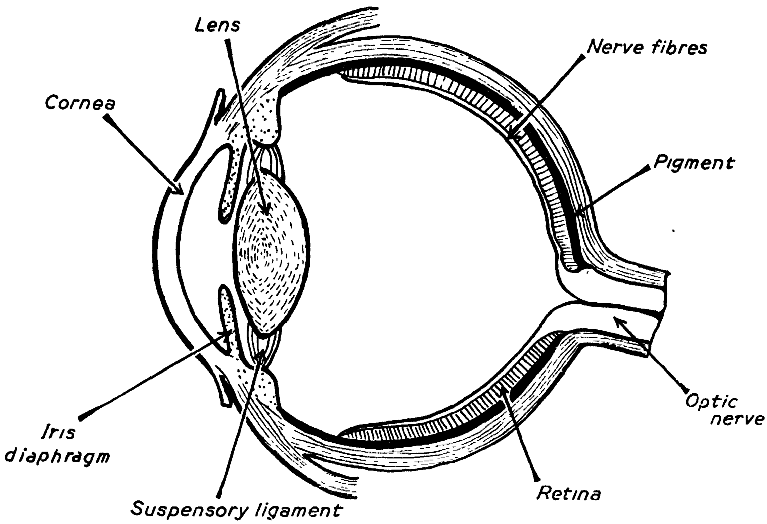

Fig. 70. Diagram of a Sagittal Section through a Human Eye, viewed from the Left Side

the **iris diaphragm** (L., *iris*, rainbow), which enables the pupil to contract when the eye is suddenly exposed to powerful illumination. The lens of the eye, unlike that in a camera, can alter its curvature and so focus objects on the retina with clear definition. **Ciliary** (L., *cilium*, eyelid) muscles increase the curvature of the lens when they contract.

Our **ears** serve not only to receive sounds but also to help us to maintain our balance. Sound waves that reach the **tympanic** (Gk., *tympanon*, drum) membrane, or ear-drum, cause it to vibrate, and these vibrations are carried across the **middle ear** by a chain of small bones. In the inner ear there is a coiled tube called the **cochlea** (Gk., *kochlias*, snail), which is supplied with fine nerve-endings which transmit the 'message' to the brain.

The **eustachian tube** communicates with the mouth and so equalizes the pressure on either side of the ear-drum.

The inner ear also consists of three **semicircular canals,** which are filled with a fluid. As we change position the fluid also moves, and so we can keep vertical even with our eyes closed. If we revolve very rapidly for some time and then suddenly stop we feel giddy because the fluid in the semicircular canals continues to move after we have stopped.

In addition to these receptors, there are many other receptors

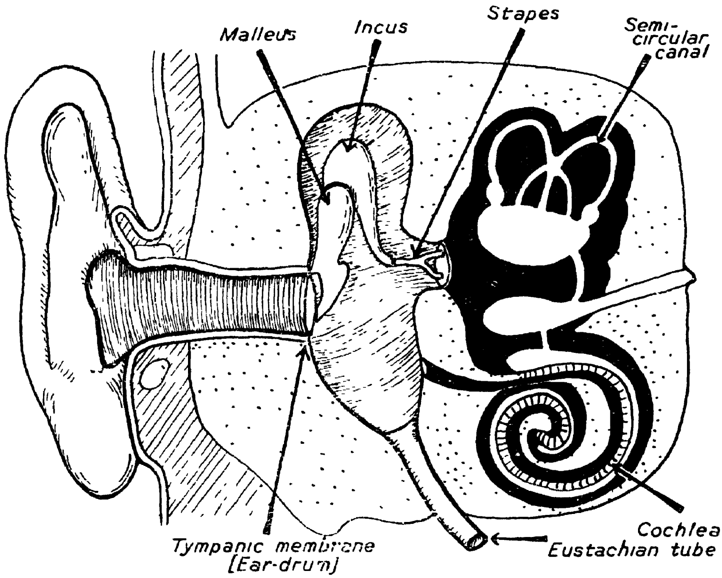

Fig. 71. Diagrammatic View of a Section through a Human Ear

This figure is redrawn after Thompson.

in animals. Taste-receptors in the tongue, heat- and touch-receptors in the skin are among the many receptors which allow an animal to appreciate its surroundings.

6. Involuntary Control

Hitherto this chapter has dealt only with the control of the muscles which normally perform voluntary actions. Yet there are many involuntary muscles, such as those which cause movements of the intestine, which are also controlled by the nervous system.

Those nerves which exert control on the involuntary activities of the body together constitute the **sympathetic** (Gk., *syn*, with; *pathos*, feeling) or **autonomic** (Gk., *autos*, self; *nomos*,

province) nervous system, which is intermingled with the rest of the nervous system. Some of the nerve fibres of the sympathetic system form a pair of nerve-chains which are situated on either side of the spinal cord and lie ventral to it. The fibres are grouped at intervals to form small swellings called **ganglia** (Gk., *ganglion*, little swelling), which serve as local brains to control near-by involuntary activities (Fig. 67). Most of the activities of our digestive systems are regulated by the influence of the sympathetic nervous system.

7. Instinct and the Behaviour of Arthropods

The complex social life of the ants, the web-building habits of spiders, and the many other intricate habits of arthropods show that the members of this phylum are, in comparison to other invertebrates, peculiarly sensitive in their responses to their surroundings. Indeed, their behaviour is often so complicated that one might attribute it to a power of reasoning similar to our own, had not many experiments shown that much of the behaviour of arthropods merely provides an instance of what we call **instinct,** a type of response which is inherited, and not learnt nor reasoned.

Many responses of arthropods seem to be responses to particular situations rather than to simple stimuli. For example, the 'pine processionary' caterpillar normally moves freely, but if it meets the trail of silk left by another of the same species it is bound to follow this trail wherever it may lead. The great naturalist Fabre succeeded in getting two of these caterpillars to follow one another round the rim of a flower-pot. The chase went on for seven days, only interrupted by pauses at night, until it was finally broken by chance.

Responses like these, which are made to particular *situations*, are called instincts. Often one such piece of behaviour would seem to act as a stimulus for another, thus establishing a chain of reactions. For instance, one species of solitary wasp, *Ammophila holosericea*, will sometimes dig a hole in the ground and, after catching and stinging a caterpillar, carry its victim there. It will then lay an egg in the caterpillar and close the hole. Each of these reactions occurs as a response to the previous act, and it is therefore easy to upset this behaviour. If another caterpillar is placed near by when the wasp is closing the hole the impulse to

bury will be given once more, and it will reopen the hole. The hole will be reclosed when the wasp reaches the bottom and sees the caterpillar already there, but reopened when it sees the other caterpillar on the ground. This may go on for a number of times, but eventually the wasp will finally close the hole.

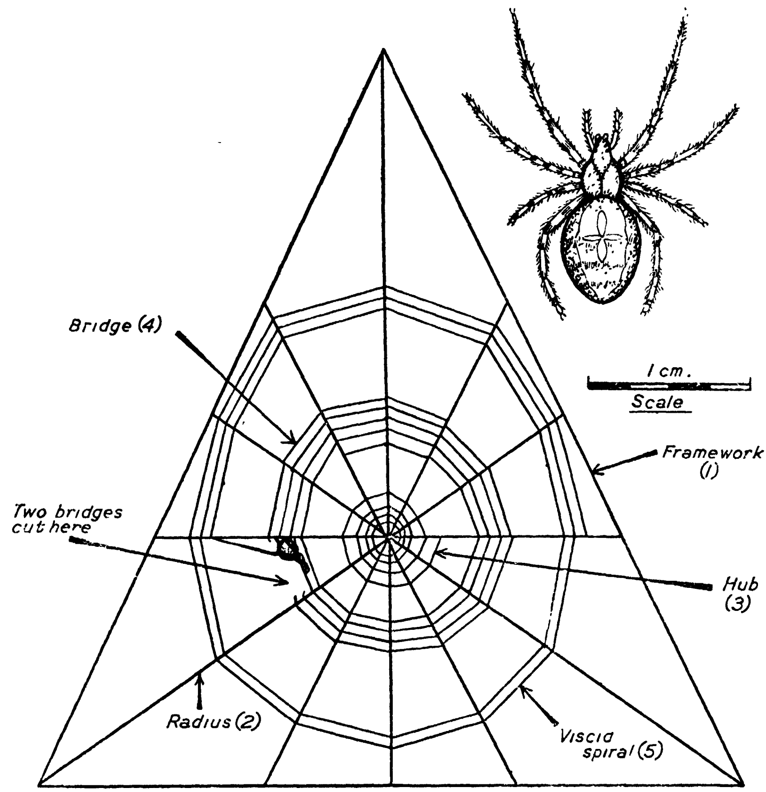

FIG. 72. WEB OF THE COMMON GARDEN SPIDER, ARANEUS (EPEIRA) DIADEMATUS, AND AN ADULT FEMALE OF THE SPECIES

The figure shows how, after two bridges have been cut, the spider does not remake them, but crosses from one radius to another by an inner bridge.

A similar chain of responses operates in the building of spiders' webs. The spider builds his web in five stages, and the completion of one stage seems to act as the stimulus for the beginning of the next.

The first stage consists of constructing a frame and attaching it to near-by objects, while a number of radii are spun from it to the centre in the second stage. In the third stage a closely-wound

spiral is then spun round the centre and holds the radii firmly. In the fourth stage a more open spiral is spun, and the radii are thus joined by a number of bridges. So far the web has been made of non-sticky silk, and serves as a framework for the sticky spiral which will trap flies and other insects. This viscid spiral is spun in the final stage, and to do it the spider must use the previously made bridges in order to cross the gaps between the radii.

If the bridges of one sector are removed the spider is quite incapable of making new bridges, but must travel in towards the centre of the web in order to cross from one radius to the next. Even if all the bridges are removed the spider will continue to spin the viscid spiral, though the result will now be a sticky mess. Set responses of this type, which cannot be modified to meet unusual situations, are very different from our own reasoning behaviour, which can select those responses which past experience has shown us to be the most suitable for any situation. Interference with the spider's web, together with other experiments in the behaviour of arthropods, reveals that these animals possess no power of reasoning, and indicate that their behaviour is rather the result of simple responses and inherited instincts.

Instinct can be studied in many other animals. Much of the behaviour of birds is regulated by instinct.

SUMMARY

(1) Receptors are organs which receive impressions from the outside world; effectors are organs which make the necessary response. The nervous system links receptors and effectors.

(2) Responses may be broadly classed under voluntary responses, involuntary responses, and instincts.

(3) The spinal cord is primarily concerned with simple reflexes; the sympathetic nervous system controls other involuntary activities; the brain influences higher forms of behaviour.

SUGGESTIONS FOR HOME STUDY

(1) Discuss the following types of behaviour: (*a*) dropping a very hot poker; (*b*) the web-building of spiders; (*c*) learning this chapter; (*d*) digestion of food. What regions of the nervous system are involved in each case?

(2) Compare the nervous systems of flies, fishes, frogs, and men.

CHAPTER XV

HORMONES AND THE GLANDS OF ANIMALS

A Sensitive Plant in a garden grew.
PERCY BYSSHE SHELLEY, *The Sensitive Plant*

SOME activities of living organisms are controlled by chemical substances which circulate round the body but control only particular activities. These chemical activators are called **hormones** (Gk., *hormao*, I excite). Each hormone probably controls only one particular type of activity. The responses of plants to light are simple instances of such chemical control.

1. THE RESPONSES OF PLANTS

Tropisms. Most plants are very sensitive to light, and will bend towards the source of illumination. Most of us have observed how plants placed in the centre of a fairly dark room will bend towards a window. A simple response of this type to a single stimulus is called a **tropism** (Gk., *tropē*, turn). The stems of plants are said to be **positively phototropic** because they bend towards light. The roots of many plants are negatively phototropic, and bend away from light.

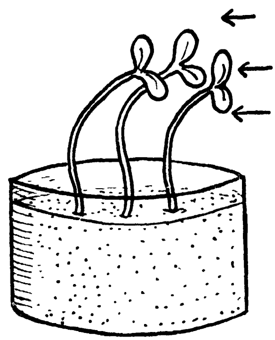

FIG. 73. PHOTOTROPISM IN CRESS SEEDLINGS
The arrows denote the direction of the incoming light.

The force of gravity is another stimulus which influences the direction of growth in plants. This response to gravity is called **geotropism** (Gk., *gē*, earth). Stems are negatively geotropic and grow against the force of gravity; roots are positively geotropic and so grow towards the centre of the earth. An apparatus called a **klinostat** is used to measure the influence of gravity, and also to show how a centrifugal force may be substituted for the force of gravity and have a similar effect.

We have not the space to consider here all the many responses of plants to external stimuli. In addition to gravity and light plants respond to temperature and to the amount of water and

mineral salts in the soil. Many plants exhibit a daily rhythm of movement by opening their flowers as the light and temperature increase and closing them again at evening, when light and temperature decrease. The crocus and the water-lily exhibit these sleep-movements plainly.

Auxins. It is interesting to consider the mechanism which enables plants to exhibit such varying responses, for the plant

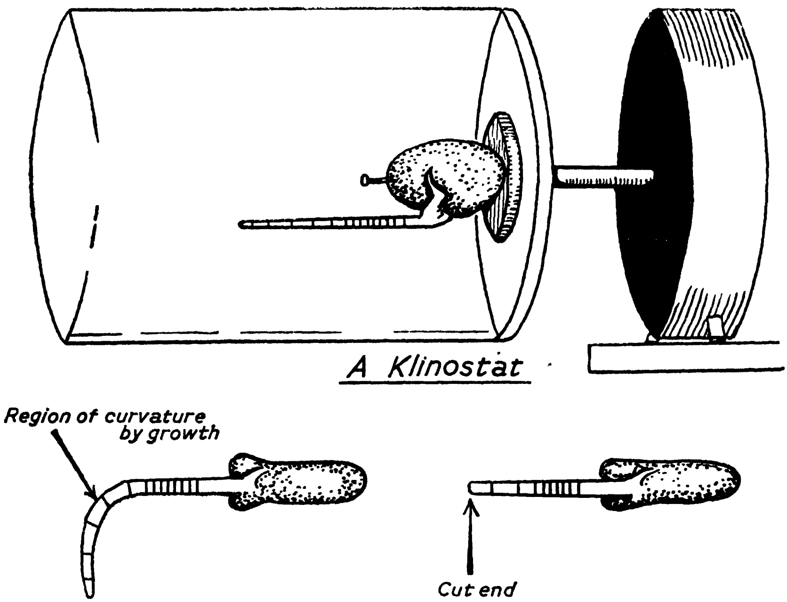

FIG. 74. EXPERIMENTS ON GEOTROPISM

The upper figure shows a klinostat in which a developing bean is being rotated at a speed sufficiently rapid to counterbalance the effects of gravity. The lower figures show a developing bean, previously marked with equidistant ink lines, to indicate the region of curvature and a decapitated bean root, showing that geotropism will not occur if the growing point is first removed.

has no obvious 'brain' or nerves. Most of the experiments on tropisms have been performed by studying phototropism, since light is a stimulus which is easily controlled. One important fact soon became apparent; one part of the plant may receive the light and yet cause another part of the plant to bend. When the growing tip of a shoot is cut off the shoot's response to light stops. When the tip of a grass seedling was exposed to light and the lower part of the plant left in shadow it was found to be the lower part of the shoot that bent. This, together with other experiments, made it clear that the tip of growing shoots is

sensitive to light, and therefore that some influence must travel down the plant to cause unequal growth when growing shoots bend towards the source of light.

A Danish investigator showed by a simple experiment that the influence which passes from the tip of a shoot down the stem does not travel along nerves. He cut off the tip of an oat seedling, covered the cut end of the stem with a layer of gelatine, and then replaced the tip of the stem. The plant which had been thus operated on could still respond to light, thus proving that the influence from the tip could travel through gelatine. Nerve impulses would probably be unable to travel through gelatine, but most soluble chemical substances can, and it was therefore suggested that the influence which travels from the tip of a stem might be a soluble chemical compound.

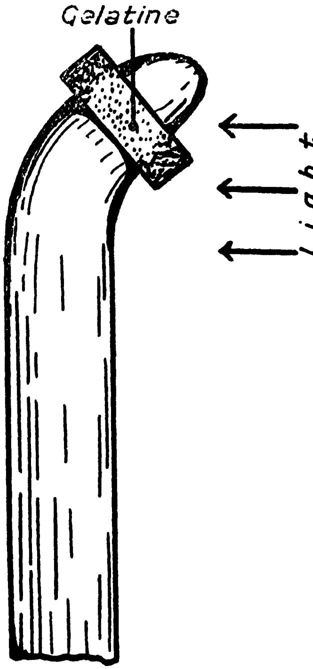

FIG. 75. EXPERIMENT TO SHOW CAUSE OF PLANT'S BENDING TOWARDS LIGHT

The above experiment demonstrates that a chemical substance passes from the growing tip of a plant down the stem, causing it to bend, when the tip is illuminated from one side. As the figure shows, the chemical substance involved will pass through gelatine.

Subsequent experiments showed that there is a chemical compound which is normally produced in the growing tips of all young shoots and stimulates growth; the effect of light is believed to cause a transference of this substance to the side of the plant which is in the shadow, causing that darkened side of the plant to grow more rapidly than the illuminated side, and consequently the stem to bend towards light.

The nature of the 'growth-chemical' produced by living shoots has now been determined, and a number of chemical compounds which have similar effects have been manufactured in the laboratory. These compounds, which are called **auxins** (Gk., *auxein*, to increase), can be bought at chemists or horticulturists under such trade names as Hortomone A, Seradix A, etc. They are especially useful to the horticulturist for the

multiplication of plant cuttings, since they encourage the growth of roots in cuttings (see Plate 10). Some domestic plants—for example, carnations—are usually multiplied by means of cuttings, and a method which will increase the formation of roots is very important to gardeners. In the practical application of this process the cut ends of shoots are first stood for some time in a diluted solution of an auxin and then planted in the usual way. It is important to regulate the strength of the hormone solution; too strong a solution would check root formation. Moreover, the growth substances will actually inhibit the growth of roots which have already formed, and they should not therefore be used on a cutting or plant which has already developed some roots.

2. Ductless Glands

Many of the 'long-term' activities of animals, such as growth, development, and reproduction, are under the chemical control of hormones, which circulate in the blood.

Patches of tissue, called **ductless,** or **endocrine, glands,** manufacture these hormones and pour them into the blood-stream as they are needed. Hormones control moulting in insects and colour-change in shrimps, but are especially important in the vertebrate animals, particularly man. The position of the ductless glands is shown by the accompanying figure.

The normal activities of the ductless glands are carefully controlled and delicately balanced. Consequently, any disturbances which lead to the under-production or the over-production of particular hormones may produce very striking effects. For instance, many giants and dwarfs are the result of over-active or under-active pituitary glands. Experimental work on the ductless glands is often rewarded by very dramatic results. Any particular hormone taken from one vertebrate will in most cases produce the same effect in other vertebrates. The implantation of a gland or the injection of an extract prepared from a gland of an animal of one species into an animal of a different species may therefore lead to very marked reactions.

There is not sufficient space here to consider the action of these hormones in detail. We can but notice a few of their more important effects.

The **thyroid** (Gk., *thyra*, door; *eidos*, form) gland, a paired body lying in the neck, controls the rate of metabolism of tissues,

and so affects development. Some of the early work on the action of the thyroid was performed on tadpoles, which will change more rapidly into frogs if they are fed on tablets prepared from the thyroid glands of sheep or some other mammal. Conversely, if

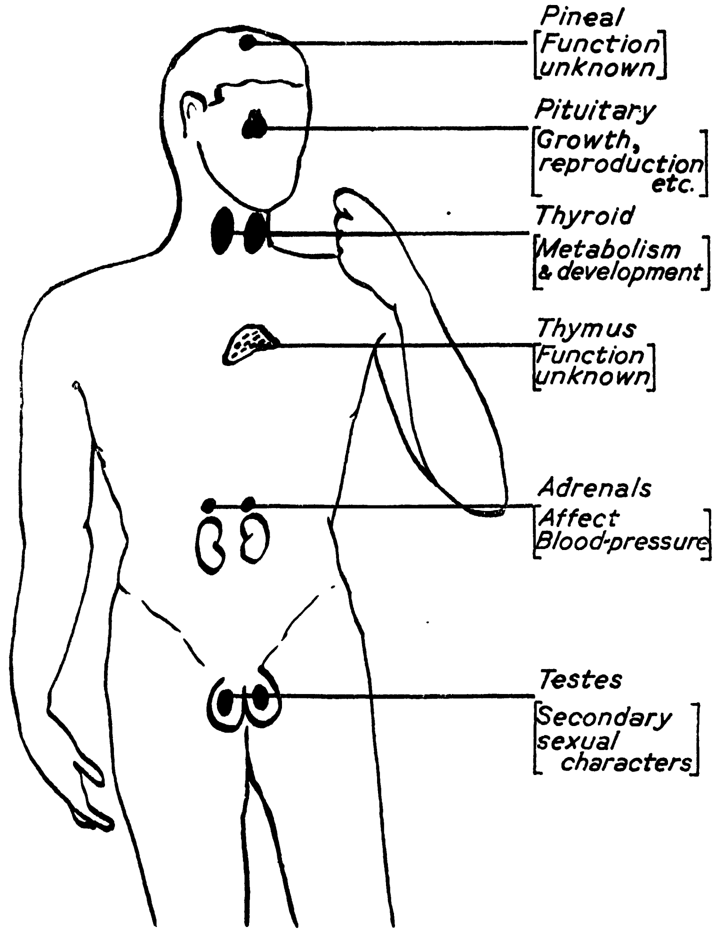

FIG. 76. DIAGRAM TO SHOW THE POSITION OF THE MAIN DUCTLESS GLANDS IN MAN

the thyroid glands are removed from tadpoles they never become frogs.

In man babies are sometimes born with under-active thyroid glands, and are consequently very backward in development. Extreme cases are little more than slobbering idiots, and are called **cretins.** It is usually possible to cure this condition by

feeding the infants with tablets of thyroid extract for some years.

The **pituitary** (L., *pituita*, phlegm) gland is the most important ductless gland, since it not only affects the activities of growth and reproduction and other functions but also exerts a controlling influence on the other ductless glands. It is known to manufacture a hormone, or hormones, which stimulates the growth of the body. Many of the dwarfs in circuses have become so as the result of an under-active pituitary gland in childhood. Conversely, many of the giants of the past and present reached their size because of an over-active pituitary during their early years.

A relatively rare disease known as **acromegaly** results from the over-activity in adult life of one portion of the pituitary gland. The bones of the face, hands and feet are particularly affected, and become greatly enlarged.

The colour responses of certain animals to their surroundings are affected by the pituitary gland. Frogs are dark in colour when on a dark background, but if they are placed on a light-coloured background they pale noticeably after an hour or so. If the pituitary gland is removed the frog will become very pale, and will only darken if pituitary extract is injected into its body.

Pituitary hormones which affect the sexual organs are produced as an animal matures. One hormone stimulates the manufacture of sperms in males and eggs in females; another pituitary hormone activates glandular tissue in the sexual organs themselves, causing them to pour sex-hormones into the blood.

The **adrenal** glands (L., *ad*, to; *ren*, kidney) each contain two distinct regions, which manufacture separate hormones with different effects. The central portion (the medulla) produces a hormone which affects blood-pressure, the amount of sugar in the blood, and the responsiveness of certain parts of the nervous system. The outer portion (the cortex) of the adrenal gland produces a hormone, or hormones, which are concerned with reproduction. There is evidence that the activity of the adrenal medulla is increased during times of emotion and strain, and it has been suggested that the consequent increased output of the adrenal hormone helps to mobilize the body to meet conditions which demand very great effort.

The **sex-hormones** affect us emotionally and bring about the development of the secondary sexual characters (p. 194). The development of hair on the face and pubic region and the breaking of

the voice which occur when boys reach puberty are brought about by the release of the male sex-hormone from the developing testes.

Certain cells in the pancreas, known as the **Islets of Langerhans,** manufacture a hormone called **insulin** and pour it into the blood stream. A deficiency in this hormone leads to the disease called **diabetes,** which is characterized by excessive amounts of sugar in the blood stream; consequently sugar is excreted in the urine, and so the reserves of the body become used up, and in severe cases death may result. The discovery of insulin by Sir Frederick Banting and Dr Best in 1921 enables doctors to control diabetes by periodic injections of this hormone.

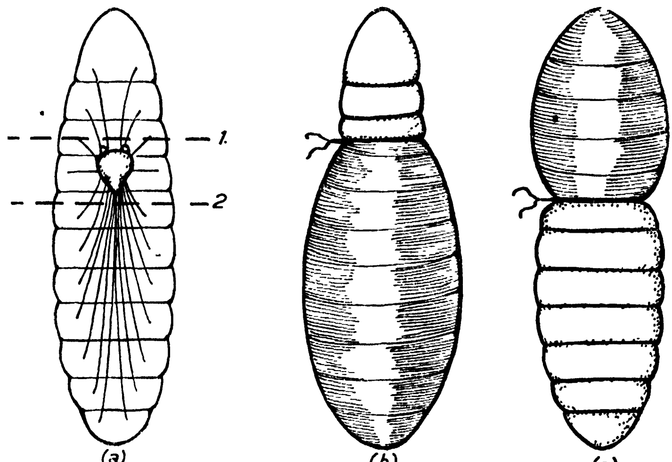

FIG. 77. PUPATION IN THE BLOW-FLY, CALLIPHORA

(*a*) Larva, showing nerve centre and the position of ligatures (1, 2); (*b*) with ligature at 1 more than sixteen hours before pupation; only the posterior region has pupated; (*c*) with ligature at 2 more than sixteen hours before pupation; only the anterior region has pupated.

The vivisection laws in Britain prevent any experiments on living vertebrates except when a licence is granted for special research. We can, however, study the action of a hormone in an invertebrate, the blow-fly, or bluebottle. Like the house-fly, the blow-fly changes from a larva to a pupa, and recent work suggests that this change is started by the release of a hormone into the blood. Experiments indicate that the hormone is manufactured by tissues in or near the brain, so if we tie a piece of thread or catgut tightly round the larva, above or below the nerve-centre, as in Fig. 77, only the posterior or the anterior region of the body will pupate.

We can show that this is not due merely to damage to the tissues by injecting some of the blood of a pupating larva into the posterior region of the individual shown in Fig. 77 (*c*). The hormone then present in the blood will induce pupation. The ligatures in these experiments must be applied more than sixteen hours before pupation begins. Otherwise the hormone will have already been released and tying the larva will not influence pupation.

SUMMARY

(1) Some of the activities of animals and plants are controlled by chemical substances called hormones.

(2) Plant shoots bend towards light but away from the force of gravity. Plant roots bend towards the earth's centre of gravity.

(3) These curvatures are brought about by unequal growth, resulting from the activity of a growth-hormone.

(4) Growth, blood-pressure, the rate of metabolism and development, are among the activities of our bodies which are controlled by hormones, the latter being produced by ductless glands.

(5) Moulting and pupation in insects and colour changes in crustaceans are affected by hormones.

SUGGESTIONS FOR HOME STUDY

(1) Compare the way in which (*a*) plants, (*b*) animals, respond to light.

(2) Give an account of two experiments to show that certain activities of living organisms are under chemical control. How can you show that the activities you name are not controlled by nerves?

CHAPTER XVI

GROWTH AND SIZE

To compare
Great things with small.
J. MILTON, *Paradise Lost*, Book II

A CONSIDERABLE increase in volume and bulk must take place before an animal or plant can reach its adult size; this process of enlargement we call **growth.** True growth involves only the absorption of food and its incorporation into the body to form protoplasm. It is usually accompanied by **development,** which involves an increase in complexity of the tissues formed.

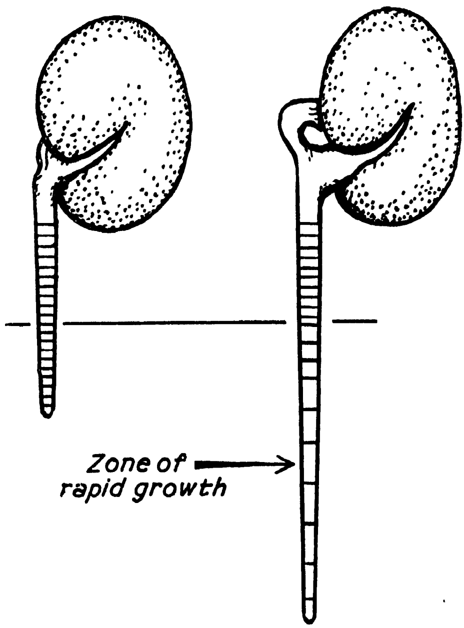

FIG. 78. REGION OF MAXIMAL GROWTH IN A BEAN ROOT

1. RATE OF GROWTH

In plants growth proceeds unequally. A period of slow growth is followed by a stage of rapid growth, which is in its turn succeeded by a further period of slow growth. We may show experimentally that this is so by observing the rates of elongation of the root and shoot in a young bean. (Experiment 1 at end of book.)

Equidistant marks are made on the shoot and the root by drawing lines in Indian ink. As the root and shoot lengthen these lines will be drawn further apart. Twenty-four hours after the lines were drawn we shall note that those midway down the root and shoot have separated the most widely, which indicates that the oldest tissues at the bases are growing but slowly, while

those at the tips have not yet reached their stage of active growth, and those which have been formed fairly recently are alone growing actively.

A comparable observation may be made on the young shoots of a rapidly growing shrub (Experiment 2). In this case the distances between successive nodes are measured. Once more we find that those tissues first formed and those recently formed have grown slowly when compared with the intermediate tissues.

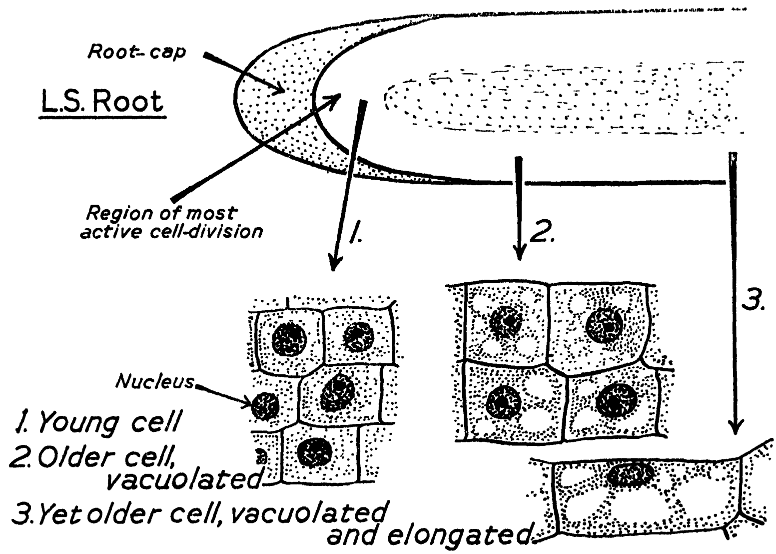

FIG. 79. DIAGRAM OF LONGITUDINAL SECTION THROUGH THE TIP OF A ROOT, SHOWING THE MAIN TISSUES

It will be noticed that as the cell becomes older it also becomes more elongated and more vacuolated. See also Plate 11.

So far we have considered only the increase in length of growing plants. A true estimate of growth must also take into account their increase in thickness. Moreover, we should attempt to distinguish between a possible temporary increase in water content and a more permanent increase in solid matter. The rate of growth in plants is, in practice, best measured by recording the dry-weights of large numbers of plants of different ages.

In plants the formation of tissues is mainly restricted to certain regions only, and so any account of plant growth must include some description of these areas of cell-multiplication.

The elongation of the root and shoot occurs as a result of the

activity of cells just behind their **apices** (L., **apex**, summit) (Plate 11). Such tissues are termed **apical meristems** (Gk., *meristes*, divider).

The apical meristems produce new cells by cell-multiplication. The cells thus formed are fairly small at first, but they expand later to form mature cells. This expansion begins with the intake of water and the stretching of the cell-wall by the pressure of its contents. The enlargement of the cell-wall is then made more

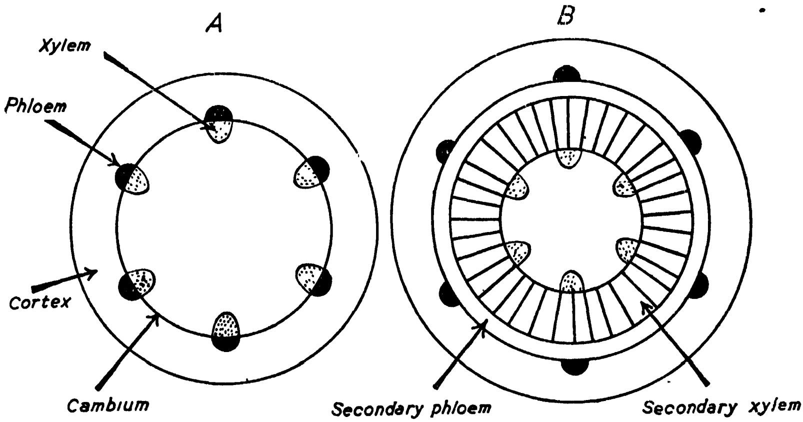

FIG. 80. GROWTH IN WOODY STEMS

A, young stem in transverse section, showing the position of the main tissues; *B*, section of a woody stem after one year's growth.

(These figures are diagrammatic, and the relative sizes of the various parts are not drawn to scale.)

permanent by the deposition on it of substances from the protoplasm of the cell. As the cell enlarges the protoplasm forms a lining to the cell-wall and vacuoles appear (Fig. 79).

The increase in girth of a flowering plant occurs through the activity of another meristematic cell-layer, called the **cambium** (L., *cambium*, exchange). This layer lies in the position shown by Fig. 80; its cells give rise to xylem tissues on one side and phloem tissues on the other.

The growth of plant cells depends on the following factors: (*a*) the presence of cells which are able to divide; (*b*) available food reserves in the dividing cells or the opportunity to obtain food from other portions of the plant; (*c*) a plentiful supply of water; (*d*) a supply of growth-hormones; (*e*) suitable conditions of temperature, oxygen supply, and light. Plants grown in darkness become flabby, long, and pale, a condition known as **etiolation.**

Growth in plants seems to be affected, and is probably controlled, by chemical substances known as auxins (p. 161). The growing tips of the root and shoot appear to exert some influence which inhibits the formation of branches from the side of the stem or root. If the tip of a shoot is cut off many side-branches may grow out from the buds in the axils of the leaves on the side of the stem. When gardeners **prune** plants they cut the tips of the main stem or branches, and so promote the formation of many more smaller branches, thus making the tree or shrub more compact and 'bushy,' and so capable of bearing more fruit.

The growth of animals differs from that of plants in some respects. Cell-multiplication is not so restricted to certain areas, but occurs fairly generally over the body. Little growth occurs after maturity, and consequently by far the greater part of growth is undergone in youth, in contrast to plants, where a certain amount of growth continues throughout life.

Trees increase in girth each year by the formation of new vascular tissue by the cambium. Since very active growth occurs only in the spring and summer, annual growth is marked by distinct rings of vascular tissue in the stem. We may, therefore, by examining the cut surface of a tree stem and counting the rings, calculate the age of the tree, and also, by examining the width of the rings, gain some idea of the climate in past years, since wide rings indicate a season which favoured rapid growth (see Plate 12).

Annual growth is seldom so easily detected in animals, though in some fishes it is possible by counting the rings on each scale to assess its probable age.

2. Cell-division

Living organisms grow by increasing the number of cells which compose their bodies. Thus, an adult man starts life as a single cell, the fertilized egg, but finishes with a body composed of about a hundred billion cells. His growth has occurred by means of the multiplication of cells by cell-division, each of the half-cells formed by a division later enlarging to the size of its parent.

There is a good reason why growth is always accompanied by cell-division and why cells should not merely increase in size without splitting. Oxygen for respiration and food materials are absorbed all over the surface of the cell, thus enabling the

inner regions to obtain those chemicals which they require. But, as a cell doubles its diameter, the surface only increases by four times, though its bulk has increased by eight times. If the diameter should be trebled the bulk would increase by twenty-seven times, though the surface-area would only increase by nine times. Since the inner part of the cell can only obtain its chemical requirements through the surface it is as though Great Britain had increased its population without increasing its port

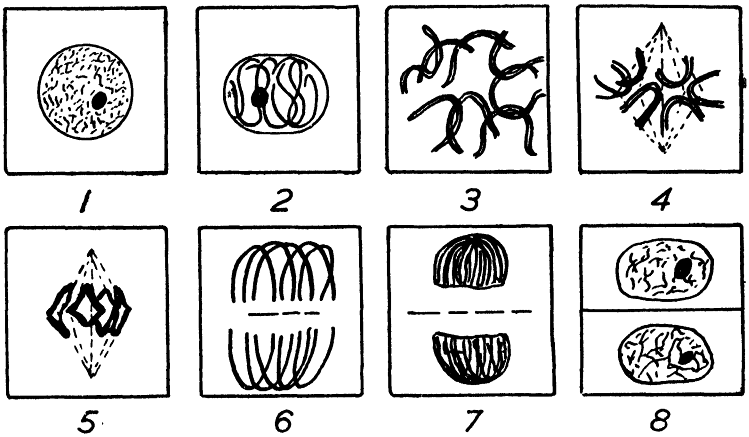

FIG. 81. DIAGRAMMATIC VIEW OF SUCCESSIVE STAGES IN MITOSIS IN THE CELLS AT THE APICAL MERISTEM OF AN ONION ROOT

facilities for importing food; the inner regions of the cell would starve unless it divided in half, and so readjusted its surface-volume ratio.

The process of normal cell-division, or **mitosis**[1] (Gk., *mitos*, thread), is accompanied by great changes in the nucleus. The process has for convenience been divided by biologists into four stages, but as it is continuous we may describe it as such. Fig. 81 shows the sequence of events. First the dark-staining material of the resting nucleus (1) loses its granular appearance and is seen to consist of a number of fine threads (2), which proceed to become shorter, fatter, and more distinct from each other (3). These threads are called **chromosomes** (Gk., *chroma*, colour; *soma*, body), and are constant in number and appearance for any one species. (For example, in man there are forty-eight, in the apple thirty-four, and in the American fruit-fly eight.[2])

[1] Cells which form gametes do so by a process called meiosis.
[2] See Fig. 142.

The thin membrane round the nucleus disappears, and fine constrictions appear in the protoplasm in the form of a spindle. Then the chromosomes, which by now have each divided into two halves, become arranged on the 'equator' of the spindle (4). The halves of the chromosomes separate and move to opposite ends of the cell (5, 6) and there form two new nuclei (7). Meanwhile a split has divided the protoplasm, and so formed two cells (8), each with a nucleus composed of the same number of chromosomes as that of the original cell. Mitosis occurs in most animal and plant cells, though there are some cases where division takes place without such complex nuclear changes.

3. Size

The range of size in living things is startling to contemplate. At one end of the scale we find the Californian Big Trees weighing nearly a thousand tons and the Sulphur-bottom whale weighing over 150 tons, while at the other end we find the bacteria, which are living organisms and yet are so small that 250,000 could rest side by side on the full stop at the end of this sentence without any overcrowding. One-quarter of the total range of size in the universe is, as far as we know, occupied by living things. A Big Tree is as much larger than a bacterium as the sun is bigger than the tree. Man is almost halfway in size between an atom and a star. The biggest single living organism is a quadrillion times larger than the smallest.

A very small size does not necessarily imply a reduction in complexity; adult insects exist complete in every detail as regards nerves, eyes, muscles, and so on, yet smaller than a human egg (·2 mm.); an ounce of fleas would contain more than 80,000 perfect individuals. One may therefore ask what factors limit the size of any species? Is there any reason why birds should not be as big as aeroplanes, or fleas the size of men?

In order to discover what principles limit the size of any species let us imagine that we could juggle with the size of some living creatures. To begin with, let us construct a man who is normally proportioned but about sixty feet high. Unless the size of this giant's leg bones were greatly increased his legs would be unable to support his weight, for while his leg bones have become about a hundred times as thick his weight has increased nearly one thousand times; to support such a weight the bones

of the leg must increase to the size of huge tree-trunks. Alternatively, imagine a bird the size of a man. In order to keep in the air such a beast would need a breast projecting about four feet to house muscles for working its wings, and even then flight would be mainly restricted to gliding on up-currents of air. The size of insects is limited by their method of respiration, since insects respire by the diffusion of oxygen along tracheæ. Under such conditions the rate of diffusion is very slow, and any portion of the insect's body that was more than a quarter of an inch from the outside air would always be short of oxygen. Consequently the bodies of insects are rarely more than half an inch thick.

If we now consider diminution in size in our subjects we should find that a mammal much smaller than a mouse would have to spend all its day eating, and even then would not be able to keep warm enough. This is because the body surface, from which heat is lost, does not shrink as rapidly as does the body weight. As it is a mouse has to eat seventeen times as much food as a man, in proportion to their body weights, eating in fact nearly a quarter of its own body weight of food every day. We may, therefore see by these few examples why a size that suits, say, an insect, would be impossible for a mammal, and *vice versa*.

4. Abnormal Growth

No account of growth and size would be complete without some mention of abnormal growth, since cells sometimes seem to lose their power of controlled growth and proceed to divide and grow at an alarming rate, even to the extent of killing the organism of which they form a part.

The swellings of tissues which are caused by abnormal growth are referred to as **tumours,** and two distinct types may be recognized in animals. The so-called benign tumours occur when the growth is localized, as in the formation of carbuncles, warts, and some other growths. More dangerous types of growths, which are called malignant tumours, take place when cells of the first tumour to form wander round the body and start other tumours. Malignant growths are generally called by the name of **cancer** (L., *cancer*, crab), a disease which kills some 220,000 men and women each year in Britain and America. Treatment consists in the removal of the cells of uncontrollable growth, either by surgical means or by killing them with radium rays or

X-rays. Sometimes, however, the tumour has formed in some vital tissue, like the lungs or liver, and no successful treatment is possible. The exact causes of cancer are as yet unknown, though each year we learn new facts about the activity of malignant tumours, which may eventually solve the problem of this disease.

SUMMARY

(1) Growth is performed by the absorption of material and its incorporation into the body to form protoplasm.

(2) In living things it is accompanied by the division of cells, so that as an organism grows the number of cells in its body increases.

(3) Respiration, heat-loss, and other factors limit the sizes of living things.

(4) Some diseases result from abnormal growth.

SUGGESTIONS FOR HOME STUDY

(1) Compare the growth of animals and plants.

(2) What factors limit the sizes of living things?

(3) Describe the process of cell-division.

CHAPTER XVII

PLANT REPRODUCTION

By their fruits ye shall know them.

St Matthew vii, 20

THE reproduction of a flowering plant when considered superficially appears to be a fairly simple process. Pollen from one flower is carried to the carpel of another of the same species, and joins with it to form a seed, which later germinates to create a new individual.

In detail, however, this method of reproduction in a flowering plant is a very complicated process, and it is only one of the three ways in which plants reproduce. Simpler plants also reproduce sexually, and sometimes asexually by the production of great numbers of cells called **spores.** Some flowering plants also reproduce by methods of vegetative reproduction.

In order to understand the relation between the different methods of reproduction in plants, and the significance of certain nuclear fusions in the flowering plants, it will first be necessary to study the phenomenon of the **alternation of generations** in plants.

1. THE ALTERNATION OF GENERATIONS

The so-called alternation of generations is well illustrated by the fern plant (Fig. 82).

On the underside of the leaves of the well-known fern plant a number of small brown bodies may be seen. Under the microscope we find that these are formed of clusters (each cluster called a sorus) of **sporangia,** each of which produce large numbers of cells called spores. These are scattered in dry weather and fall to the ground, where they may each form a new plant. The plant which develops from a spore is not at all like the usual fern plant, however, but is a small, flat, heart-shaped green plant measuring about a quarter of an inch across, which is attached to the ground by root-like hairs. This plant, called the **prothallus** (Gk., *pro*, before; *thallos*, young shoot), bears a number of male and female reproductive organs on its lower surface. The male organs (♂) form spermatozoids, while the female organs (♀)

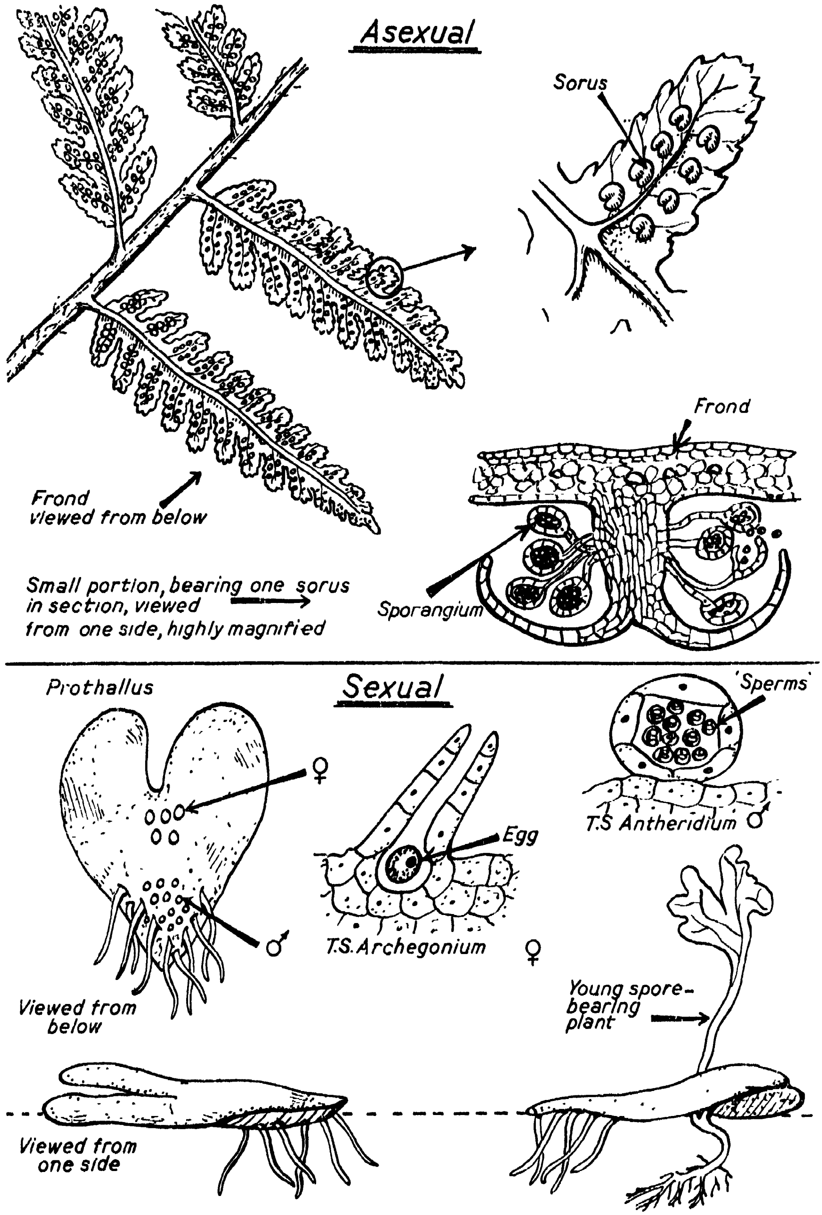

FIG. 82. LIFE-HISTORY OF THE FERN

For explanation see pp. 175, 177.

each contain an egg. In damp weather, when there is a film of water on the prothallus, spermatozoids swim to the eggs, and each egg may be fertilized by fusion with a spermatozoid. Only one

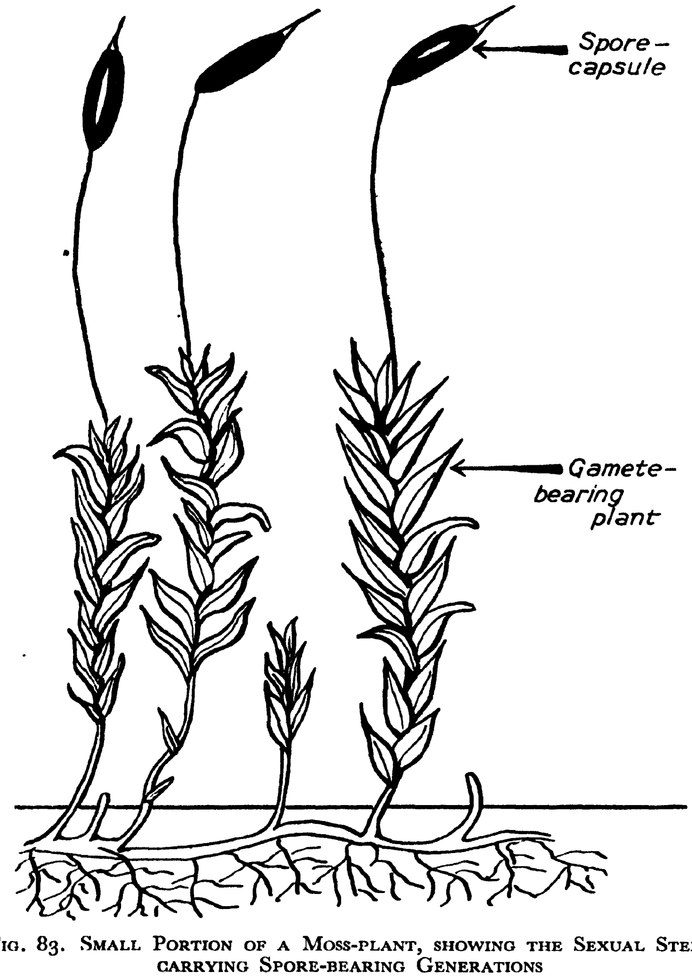

FIG. 83. SMALL PORTION OF A MOSS-PLANT, SHOWING THE SEXUAL STEMS CARRYING SPORE-BEARING GENERATIONS
The magnification is approximately five.

fertilized egg develops on each prothallus. It forms in time the familiar large fern plant, which in its turn will form more spores and so continue the alternation of an asexual generation producing spores, and a sexual generation forming eggs and sperms.

Mosses exhibit a somewhat similar alteration of generations,

except that in this case the main plant forms eggs and spermatozoids while the asexual generation, consisting of a stalk bearing a sporangium, remains attached to the parent sexual plant (Fig. 83).

In flowering plants the reverse is the case. The flowering plant is spore-producing, but some spores remain attached to the flower

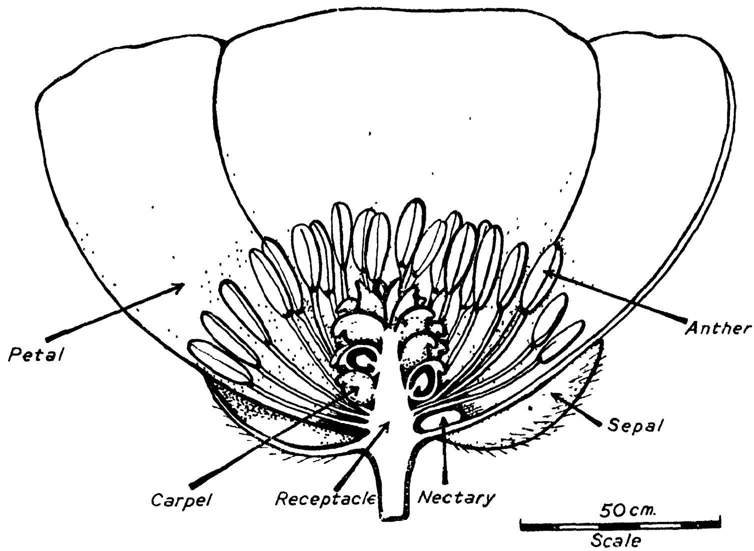

FIG. 84. VERTICAL SECTION THROUGH THE FLOWER OF RANUNCULUS ACRIS, A MEADOW BUTTERCUP

Two carpels have been opened in order to show the enclosed ovules.

and form embryo-sacs within carpels (see Fig. 87), while others form pollen grains. The whole process of an alternation of generations is very much reduced and obscured. The spores do not appear as such and the sexual generation and gametes are only represented by nuclei.

2. THE FLOWER

Sexual reproduction is found in all the **phyla** of plants. In the largest phylum, that of the flowering plants, the flower contains the sexual organs.

A typical flower[1] consists of a number of parts arranged in nearly concentric circles, called **whorls.** The outermost whorl

[1] An elementary outline of the anatomy of the flower has already been given in Chapter III.

is composed of leaf-like structures, the **sepals,** which enclose the flower in the bud stage. Inside these are the **petals,** which are likewise leaf-like in form, and are often brightly coloured.

Within the petals we find a number of **stamens,** which constitute the male reproductive organs. In the centre are placed the female organs, or **carpels.**

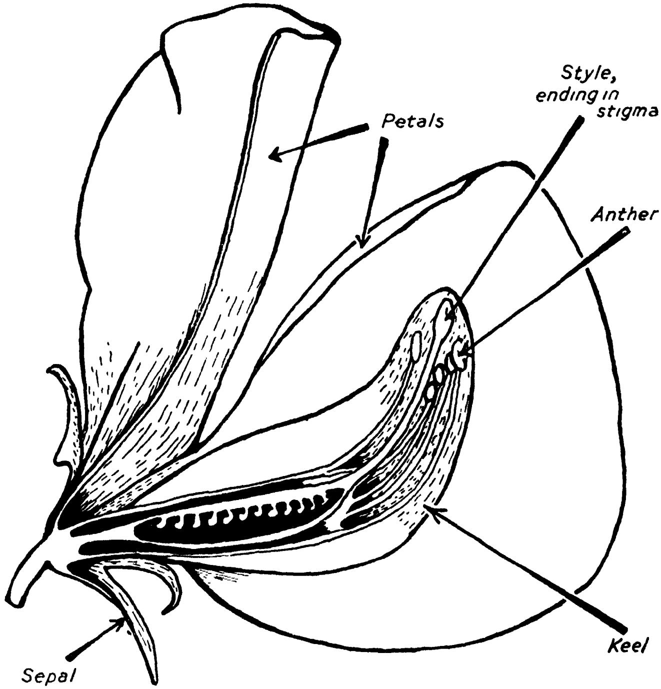

FIG. 85. VERTICAL SECTION THROUGH THE FLOWER OF THE SWEET PEA, LATHYRUS ODORATUS
The magnification is two.

The flower of a species of buttercup (*Ranunculus acris*) presents a fairly typical appearance (Fig. 84), with sepals, petals, stamens, and carpels regularly arranged, in contrast to the flower of the sweet pea (*Lathyrus odoratus*), which has become modified and has lost its original symmetry. Flowers which are symmetrical about several planes, like the buttercup, are said to be **actinomorphic** (Gk., *aktis*, ray; *morphe*, shape), in contrast to types like the sweet pea, where the flower can be divided in one plane only, if halves are to be formed. This last condition is termed **zygomorphic** (Gk., *zygon*, yoke).

Collective terms, which include parts of a flower that are distinct from the remainder, are used to simplify description. Thus we call all the sepals the **calyx**; all the petals form the **corolla**; the stamens constitute the **andrœcium** (Gk., *aner*, male; *oikos*, house); and the carpels comprise the **gynæcium** (Gk., *gyne*, woman). If the description is based on these facts the

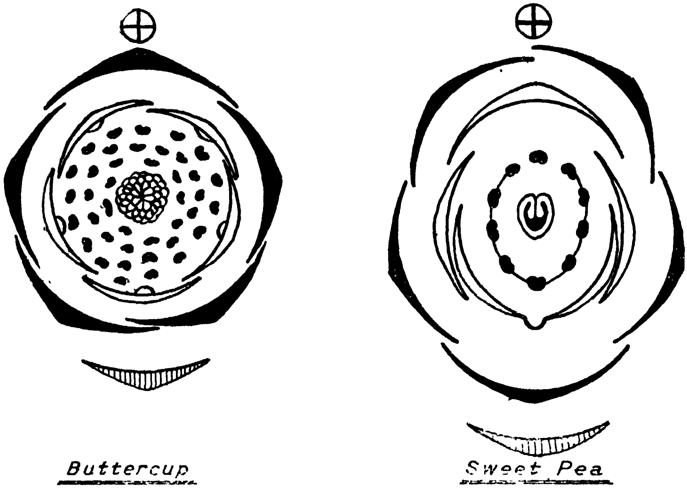

FIG. 86. FLORAL DIAGRAMS OF THE MEADOW BUTTERCUP, RANUNCULUS ACRIS, AND THE SWEET PEA, LATHYRUS ODORATUS

Floral diagrams show the main constituents of a flower viewed from above and simplified.

composition of a flower may be indicated by floral formulæ, like that of the buttercup:

$$K5\ C5\ A\infty\ G\infty$$ [1]

and the sweet pea:

$$K5\ C5\ A10\ G1.$$

The numbers of the constituents of the calyx (K), corolla (C), andrœcium (A), and gynæcium (G) are thus recorded.

We may now examine these parts in greater detail. There is considerable variation in the structure of flowers; sometimes the calyx is brightly coloured, sometimes it is absent; the corolla is usually brightly coloured when it is present, but in some species it is absent. The stamens are very constant in form; each consists of a slender stalk, the **filament,** broadening at its apex into a **connective,** which bears two **anther** lobes. The anthers

[1] ∞ signifies a large and variable number.

contain compartments called **pollen sacs,** within which the **pollen grains** develop. The gynæcium consists of one or more carpels (which may unite to form an **ovary**), each of which contains one or more **ovules.** The carpel wall, which serves for protection, is drawn out at one end into a fine tube, the **style,** which terminates in a sticky opening, the **stigma.**

When the ovule is ripe it contains seven nuclei, arranged in the manner shown by Fig. 87. Two of these nuclei, after fusion

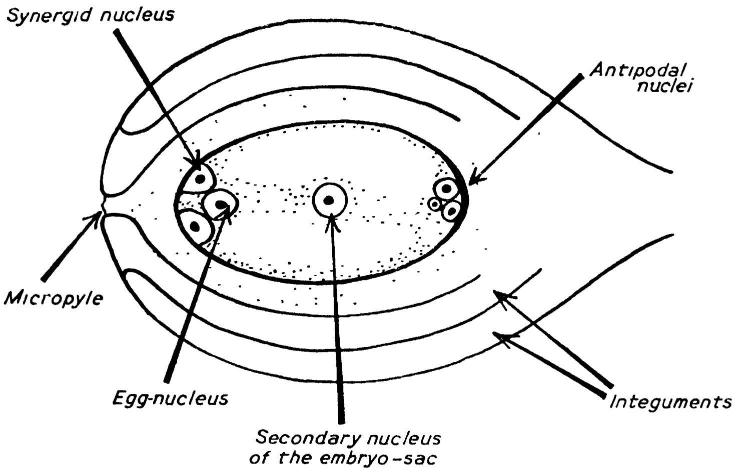

FIG. 87. DIAGRAM TO SHOW THE MAIN CONSTITUENTS OF A RIPE OVULE
The Ovule is here shown in section, and the embryo-sac can be seen, protected by integuments.

with nuclei in the pollen grain, develop, and together form a new plant.

3. POLLINATION

The process of pollination is dependent upon the arrival of pollen grains from one flower on the stigma of another of the same species. The pollen may be carried from one flower to another by insects, by wind, or, more rarely, in the case of some species, by birds or water.

Insects visit flowers in search of food, and pollination takes place incidentally as they travel from one flower to another. Flowers provide two forms of food, nectar and pollen. Nectar is a solution of sugars which is produced in nectaries. Insects, like bees and butterflies, which visit flowers for nectar, have sucking mouth-parts in the form of long tubes, through which

nectar is drawn up. Flowers that are pollinated by insects usually have large petals, which are often brightly coloured. There is evidence to show that the colours of the petals serve to attract insects to the flower. Experiments on the honey-bee have shown that while it can distinguish between the colours blue and yellow, it probably cannot distinguish red colours. It is therefore interesting to note that flowers visited by bees are usually blue, purple, orange, yellow, or sometimes white; they are rarely pure red. Flowers pollinated by butterflies, on the other hand, are often red (maiden pink, red campion), though butterflies also visit yellow, purple, or blue flowers. Night-flying moths usually visit white flowers (honeysuckle, white campion). There is also some evidence that insects are attracted to flowers by their scent.

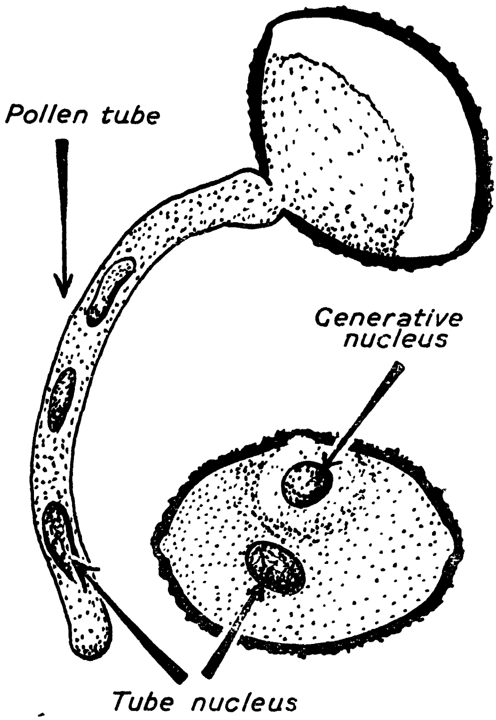

FIG. 88. POLLEN GRAIN

Above the grain can be seen germinating to form a pollen-tube. In both cases the covering of the pollen grain has been removed on one side in order to reveal the contents.

Many flowers are so constructed that when insects visit them for nectar the anthers and the stigma are made to touch the body of the insect. The sweet pea (see Fig. 85) is a highly-specialized bee-flower with an elaborate pollination mechanism. The insect alights on those petals which are called wings, and in depressing them depresses the petal called the keel, thus exposing the anthers and the stigma. As the insect probes for nectar at the base of the stamen-tube its underside is first struck by the stigma, which collects any pollen already present on the bee, and then by the style, from which pollen is brushed by the hairs on its body. The buttercup is visited by many species of insect which can effect pollination.

4. Fertilization and the Seed

When pollen grains alight on a stigma they are stimulated to develop by the sugary solution it possesses. Each pollen grain contains two nuclei; one of these, the **tube-nucleus,** controls the formation of a long pollen-tube, which passes down the style to the ovule. It eventually passes through the micropyle, and so reaches the embryo-sac.

Meanwhile the other nucleus, the **generative nucleus,** has divided to form two male nuclei, which enter the ovule. One fuses with the egg nucleus in the ovule, the other fuses with the secondary nucleus. The product of the former fusion becomes the new plant, while that of the latter fusion becomes tissue called **endosperm** (Gk., *endon*, within; *sperma*, seed), which nourishes the embryo plant. These fusions of nuclei complete the process of fertilization.

Immediately after fertilization the fertilized egg-nucleus divides rapidly, and forms a small embryo. At the same time the endosperm increases by means of cell-division. In some seeds the endosperm remains outside the embryo, while in others it becomes incorporated in the seed-leaves of the latter. The fertilized ovule containing the young embryo is called a **seed**; one or two integuments of the ovule form a hard seed-coat or **testa** (L., *testa*, shell). The embryo within the seed soon stops developing, the seed loses water, and the seed-coat hardens. The seed is then said to be ripe, and will remain dormant without obvious changes until germination. The germination of a seed has already been described (p. 36).

5. The Fruit

After fertilization changes take place in the ovary, and sometimes also in the receptacle, the bracts (floral leaves), or perianth (the calyx and the corolla), to form a **fruit.** This structure encloses the seeds until they are ripe and often aids their dispersal.

It is convenient to divide fruits into two groups—(1) **dry fruits,** (2) **succulent** or fleshy **fruits,** these terms describing their condition when ripe. The fruits of the buttercup belong to the dry fruit group. The hazel and the beech form dry fruits called **nuts,** which possess a hard outer wall. Plums, oranges, apples, and peaches are some examples of succulent fruits.

Fruits are often so formed that they themselves aid the dispersal of the seeds they contain. The tufted fruits of the dandelion and the winged fruits of the sycamore will sail in the wind for a considerable distance. Pea-pods split with violence and eject their contained seeds ; the fruits of cleavers are covered with fine

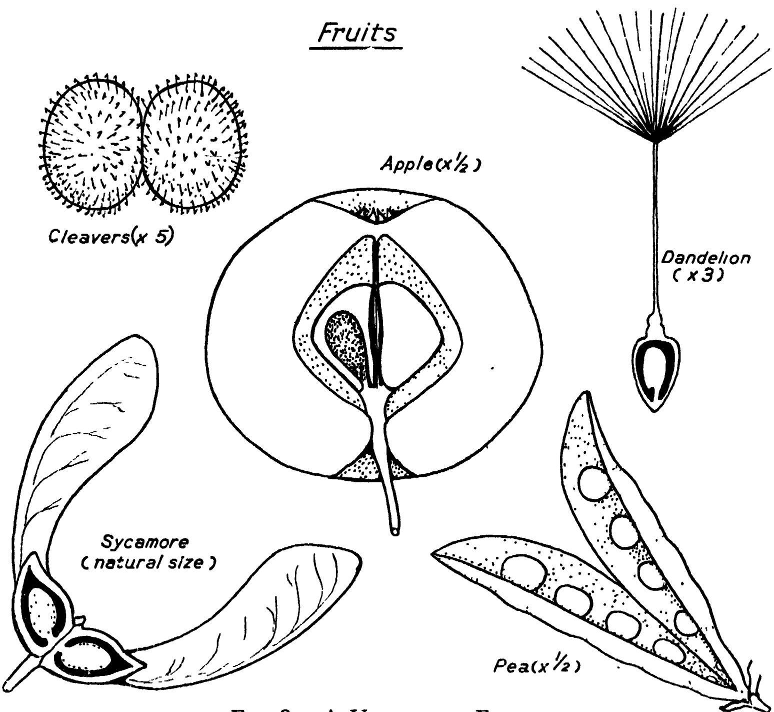

FIG. 89. A VARIETY OF FRUITS

The dandelion (*Taraxacum officinale*) and the sycamore (*Acer pseudoplatanus*) provide examples of wind-borne fruits; the fruits of cleavers (*Galium aparine*) are provided with small hooks, which catch in the fur of animals; the fruits of the pea are expelled by the splitting of the pod; the fleshy covering of the apple tempts animals to eat the fruit and so to disperse the seeds.

hooks, by means of which they cling to the fur of animals and are carried away from the parent plant.

Finally, there are very many fleshy fruits where the food materials which are contained act as a bribe to tempt animals to eat the fruit. The seeds pass unharmed through the alimentary canal of the animal and are passed out with the fæces. Many fleshy fruits are even brightly coloured, thus advertising the free gift of food offered to any animal which will eat the fruit and so disperse the seeds.

6. Vegetative Reproduction

When a portion of a plant becomes detached and forms an independent individual we may say that vegetative reproduction has occurred. Some flowering plants spread or persist from year to year by means of various modifications of this method. A few types of vegetative reproduction may be summarized here.

(1) **Runners.** Strawberry plants spread by means of creeping

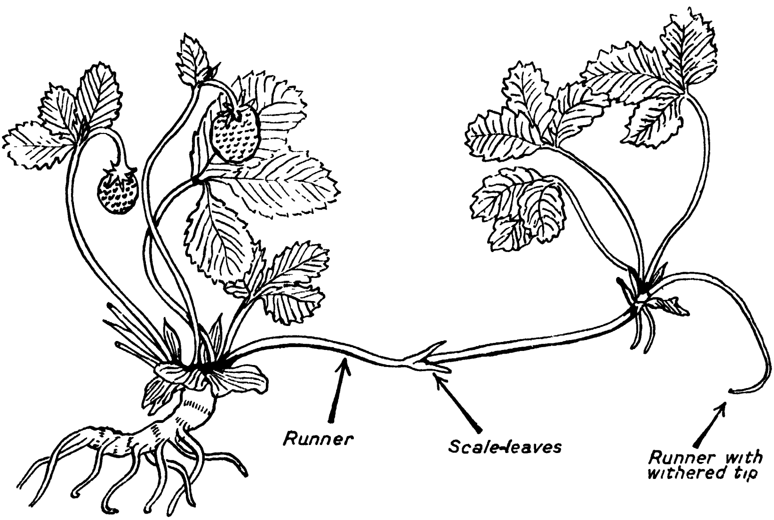

Fig. 90. Strawberry Plant

horizontal stems called runners. These stems arise from the axil of one of the leaves of the parent plant. At intervals buds on the runners grow into new plants, which later become detached and independent of the parent plant.

(2) **Tubers.** The potato plant bears a number of branches of the stem which penetrate into the ground and swell at their tips. These swellings, called tubers, are filled with starch; they remain in the ground until the following season. The 'eyes' of the potato tuber are scale-leaves with axillary buds which will grow into new shoots.

(3) **Bulbs.** Tulips and onions persist from year to year by forming bulbs. A bulb is the swollen base of the stem surrounded by fleshy leaves filled with food material. At the apex of the stem there is a terminal bud which will grow into a new plant. As it becomes a fully grown plant it will pass down food materials to

the bulb, and so nourish small axillary buds which will form new bulbs.

7. Cuttings and Grafts

Man employs a method allied to vegetative reproduction when he multiplies his garden plants by taking '**cuttings**' from them.

A cutting consists of a small portion of a shoot, which is cut off just below a node and bears a terminal bud. The cutting is

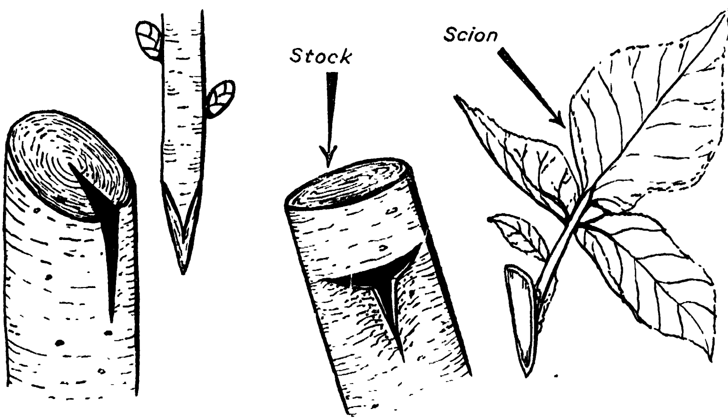

Fig. 91. Methods of Grafting in Plants
On the left a small shoot is about to be grafted on to a stock; on the right a leaf with its axillary bud forms the scion.

planted with the severed end in the soil, where it develops new roots. Some plants, such as willows and roses, readily develop from cuttings, while apples, pears, and others are not easily raised from them. Gardeners also employ artificial vegetative reproduction when they **graft** a shoot of one plant on another plant of the same species. That plant still growing in the soil is called the **stock,** while the shoot grafted on it is termed the **scion.** The cut ends of the scion and stock are shaped to fit each other and then bound tightly together so that close contact between the tissues is maintained. The graft is often covered with wax to prevent loss of water.

Sometimes the scion is not a complete small branch, but only a bud in the axil of a leaf (Fig. 91).

Buds are young undeveloped shoots. The tips of stems bear apical or terminal buds, which by their activities can cause the shoots to lengthen. Axillary buds, which are found in the angles between leaves and stems, sometimes grow out to form branch

stems. Usually the activity of an axillary bud is retarded by the presence of the terminal bud on the shoot, but if this should be removed the axillary buds may develop to form side-branches. In certain cases gardeners encourage bushy growth in shrubs and trees by cutting the terminal buds from off the shoots.

Axillary buds assume particular importance in those trees and

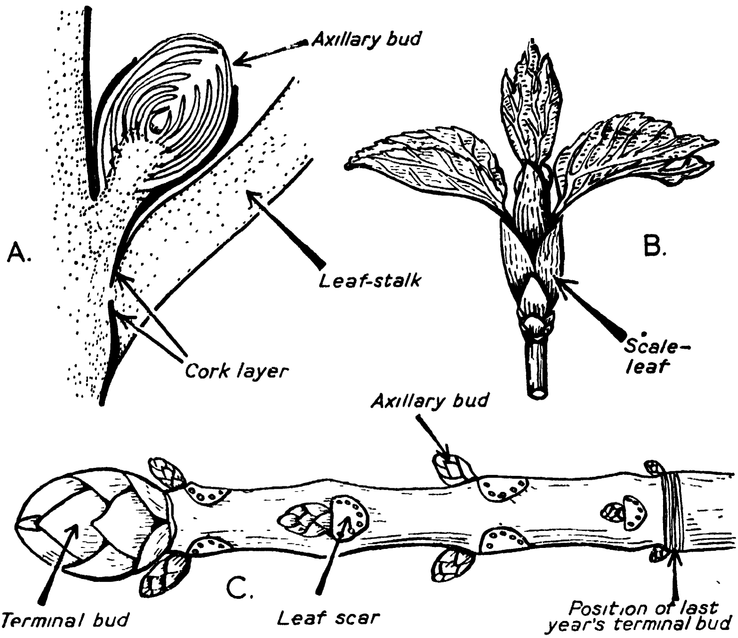

FIG. 92. BUDS

A, a section through an axillary bud of a sycamore shoot, showing the manner in which the growth of the cork layer across the leaf-base prepares the shoot for the leaf-fall in autumn; *B*, terminal bud of a sycamore shoot opening in spring. Young green leaves are shown emerging between the brown scale leaves; *C*, a shoot of the horse chestnut-tree in winter, showing the position of the terminal bud, the lateral buds, and the scars of the previous year's leaves.

shrubs which lose their leaves in the autumn. The process of leaf-fall is brought about by the growth of a thin **abscíss** layer in the stem at the base of each leaf-stalk; the development of the absciss layer is accompanied by the formation of a thin layer of cork beneath it. The development of these layers prevents the loss of water from the stem to the leaf, which therefore drops off. Meanwhile the axillary and terminal buds remain until the following spring, when they may develop into shoots bearing leaves (Fig. 92).

The propagation of plants by means of the grafting of one

plant on another has important practical applications. If one variety of apple is grafted on another a tree may be produced which combines the best qualities of each variety. Careful choice of apple root-stocks and scions allows us to influence the vigour of trees, the age at which they fruit, and the colour and quality of the apples which they produce.

Sometimes unions between plants of different species are possible by grafting methods. By grafting a grape-vine on the root-stock of a wild species of grape we can retain the fruit qualities of the former while protecting it from a serious vine disease caused by an insect of the genus phylloxera. Many ornamental plants are produced by interspecific grafts. The union of a purple broom plant and a yellow laburnum gives rise to a plant with intermediate characters.

SUMMARY

(1) Plants reproduce sexually and asexually. In the land plants an asexual generation precedes and succeeds a sexual generation. In the flowering plant the sexual generation is greatly reduced.

(2) Flowers are built on the same plan, but are modified in different species.

(3) Fertilization is accompanied by complicated fusions between nuclei in the pollen grain and those in the ovule.

(4) The fertilized ovule, together with the carpel wall, or the receptacle, constitute the fruit, which may be modified according to the mode of dispersal of the seed contained in it.

(5) Plants can reproduce vegetatively. Some of their methods of doing so are discussed in this chapter.

SUGGESTIONS FOR HOME STUDY

(1) What is meant by an alternation of generations? Give examples of its occurrence.

(2) Discuss the structure of a flower and indicate the functions of the different parts.

(3) Give an account of vegetative reproduction in plants.

CHAPTER XVIII

ANIMAL REPRODUCTION

I was ever of opinion, that the honest man who married and brought up a large family, did more service than he who continued single and only talked of population.

O. GOLDSMITH, *The Vicar of Wakefield*

ANIMALS, like plants, reproduce their kind. In animals sexual reproduction is more common than asexual, although the latter method also occurs in lower forms.

1. EARLY THEORIES

It is fairly easy to observe the way in which some animals enter the world. For instance, we may watch a hen lay an egg; we may see her sitting on the egg to keep it warm, and, after some time observe a chicken appearing from the egg. It seems clear from this that the chicken has been formed in some way partly by the body of the mother and, since hens will only lay fertile eggs if there is a male bird, the cock, in the hen-run, it is apparent that the male bird has contributed to the formation of the chicken.

The reproduction of some animals, however, is less evident, and early workers therefore believed that certain animals might arise spontaneously from non-living matter. Aristotle therefore divided animals into two groups—those which formed their young as the result of a mating process between a male and a female and those which, he asserted, arose spontaneously from mud, water, vegetable juices, or excrement. In this latter group he placed most molluscs, sea-anemones, starfishes, butterflies, many species of worms, and some other invertebrates. Belief in the possible spontaneous generation of some animals persisted for many hundreds of years. Even well-known scientists (such as van Helmont) supported traditional recipes for 'making' living things, like that for making mice by placing cheese and dirty linen in a closed receptacle. It was widely believed that flies arose from rotting meat or from vegetable juices. In the seventeenth century an Italian scientist, Francesco Redi (1626–98), showed that if rotting meat were covered with fine muslin so that no flies could reach it none were formed in the meat.

Uncovered meat 'produced' flies because eggs had been laid in the meat. These and later researches disproved the spontaneous generation theory in respect of the larger forms of life. Experiments on the minute living things we call bacteria (see Chapter XX) were more difficult to devise, and as late as the nineteenth century scientists disputed whether or not these organisms could arise spontaneously from non-living nutrient broth. One careful experimenter named Spallanzani (1729–99) had shown that by boiling such broths and then excluding air the appearance of bacteria could be prevented. His views were violently opposed by an English Catholic priest named Needham and an enthusiastic but often inaccurate Frenchman, the Comte de Buffon, who together based a network of speculation on the results of one bad experiment. They performed Spallanzani's experiment, but they used insufficient heat to kill any bacteria already present in their broth, and they stoppered the flasks with porous corks, which allowed bacteria to enter.

The theory of spontaneous generation was finally overthrown by Louis Pasteur (1822–95) (p. 211). He repeated the experiments of Spallanzani and Needham, making sure that no living bacteria remained in the flask by boiling and by arranging his apparatus in such a way that air could enter but that bacterial spores were excluded (see Fig. 104).

It is now a well-established fact that **living things can only be formed from other living things.** We call this the principle of **Biogenesis** (Gk., *bios*, life; *genesis*, descent).

The part played by the female animal in the formation of young is often more apparent than the contribution of the male. Aristotle erroneously suggested that the female contributes the 'substance' of a child and that the male imparts some 'form' which need not be accompanied by the contribution of any material from his body. The discovery of the microscope in the seventeenth century enabled Leeuwenhoek (see p. 205) and other observers to detect the presence of tiny structures which we call **sperms** in the fluid which the male emits during the act of mating. Clearly, therefore, the male contributes material for the formation of the young, and so some workers then suggested that the sperm might contain the 'substance' of the young while the female imparted the 'form.' The supporters of this theory sought to justify their view by descriptions of the tiny figures which they believed that they could distinguish in the head of the sperm.

The invention of more powerful microscopes has enabled scientists to show that sperms do not contain tiny figures, as some early workers believed and, moreover, that sperms are in fact special cells formed from other cells in the body. The 'head' of the sperm consists of little more than a cell-nucleus, which bears a whip-like tail to enable it to move actively.

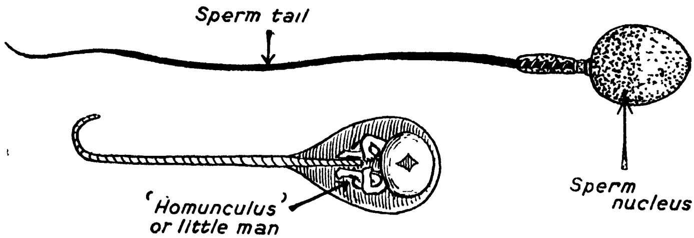

FIG. 93. THE HUMAN SPERM

The upper diagram shows the structure of a human sperm; the lower is the seventeenth-century impression of a sperm, when it was believed that a little figure could be distinguished inside. Later work, however, with better microscopes, showed this view to be false.

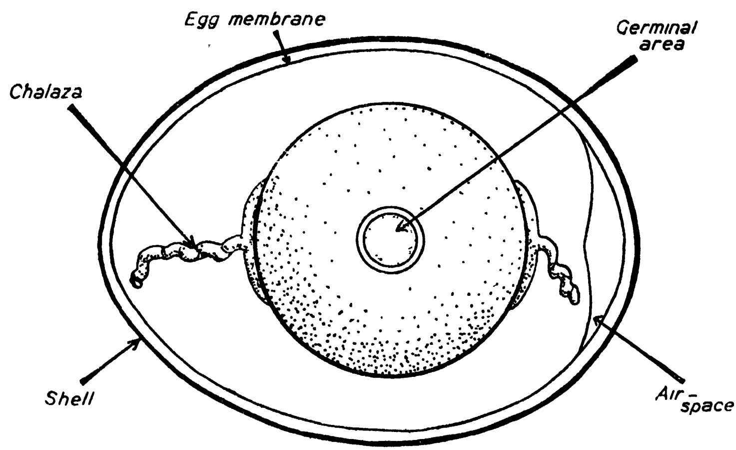

FIG. 94. DIAGRAMMATIC REPRESENTATION OF A SECTION THROUGH A HEN'S EGG

See also Plate 15.

The eggs produced in the female's body are also special germ-cells, and are derived from cells similar to the other body-cells. The size of the egg depends on the amount of food which is present stored as yolk for the use of the developing young.

Aristotle's view that one sex contributes the 'substance' of the young and that the other sex imparts 'form' is no longer tenable. It is now recognized that all young animals that are reproduced

sexually are formed by the fusion of two cells, one the egg, or **ovum,** which is formed in the body of the female, and the other the sperm, which is formed in the male's body. The production of young by the fusion of two germ-cells in this way is called sexual reproduction.

The simplest animals can reproduce by asexual methods.

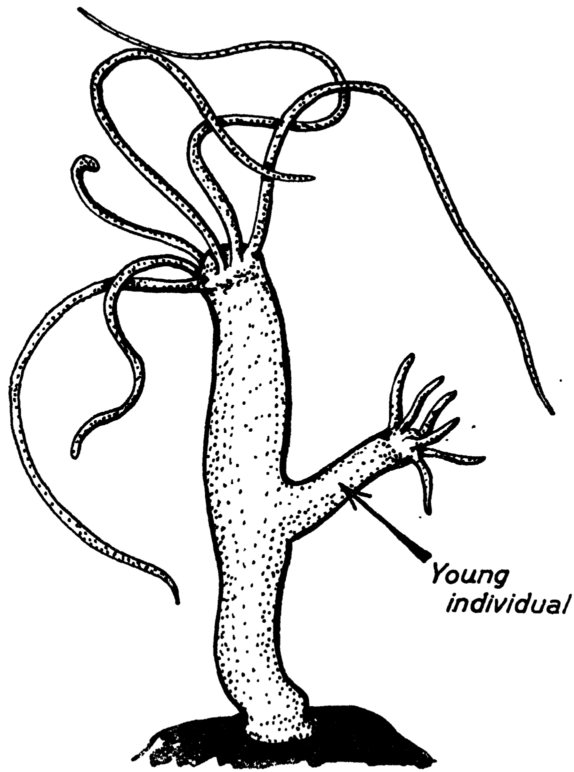

FIG. 95. ASEXUAL REPRODUCTION IN HYDRA
The smaller individual, developed from a bud, has not yet broken away from the parent. See also Plate 13.

2. ASEXUAL METHODS

The simplest form of asexual reproduction occurs when an organism splits into two halves, each of which later becomes like its parent. We can observe this process in bacteria (p. 210) and in some of the smaller forms of pond-life (p. 226). This process of division is called **binary fission** (L., *fissus*, cleft), and is said to be asexual because it does not involve the fusion of differentiated cells.

SUMMARY

(1) By using glass lenses singly or in combinations scientists in the seventeenth century discovered the details of structure in living things, which were invisible to the naked eye.

(2) Certain men had a great influence on biology by their discoveries with the microscope. Hooke, Grew, Malpighi, Swammerdam, and van Leeuwenhoek are especially famous for their work.

SUGGESTION FOR HOME STUDY

Write an account of the lives of Malpighi, Swammerdam, and van Leeuwenhoek and discuss the importance of their discoveries.

CHAPTER XX

BACTERIA AND VIRUSES

> Now I will explain to you what the law of diseases is, and from what causes the force of disease may suddenly gather itself up and bring death-dealing destruction.
>
> LUCRETIUS, *De Rerum Natura*

THE size of a living organism bears no relation to its influence on other living things. The soil, the air, water, and the bodies of animals contain countless minute organisms, without which life as we know it would be impossible. These **bacteria** (Plates 23 and 27) (Gk., *bakterion*, small rod), as they are called, bring about the decay of dead organisms and change the chemical substances contained in them to a form in which they may be absorbed by living plants. Bacteria also bring about chemical changes in other organic materials, and so cheese and vinegar are made from milk and sugar respectively through their agency, while they also influence many other industries. Many bacteria live only in the bodies of man and other animals, where they may cause diseases to occur.

Some other, even smaller, organisms, called **viruses** (Plate 27) are also found in living bodies, and cause disease in animals and plants. Viruses, in contrast to bacteria, have not been observed to reproduce outside living organisms. When we speak of diseases caused by microbes or germs we generally refer to those caused by bacteria or viruses, although, strictly speaking, the terms microbe and germ could refer to any small organism which causes disease.

1. BACTERIA

Individual bacteria are too small to be seen by the naked eye. The different types of bacteria range in size from $0{\cdot}5\mu$ to 10μ in length. Even by using a microscope we can see but little of their internal structure, though we can distinguish their shape.

Bacteria fall roughly into three groups, their position in one or other depending on whether they are spherical, cylindrical, or spiral in shape:

(1) **The Coccus** (Gk., *kokkos*, seed). Spherical forms are called cocci. They either group together in clumps like bunches

of grapes (staphylococci) or are attached to one another like a string of beads (streptococci).

(2) **The Bacillus** (Plate 23) (L., *bacillum*, small stick). Rod-shaped forms are called bacilli; some are provided with fine, whip-like hairs which help them to move, though the majority are stationary.

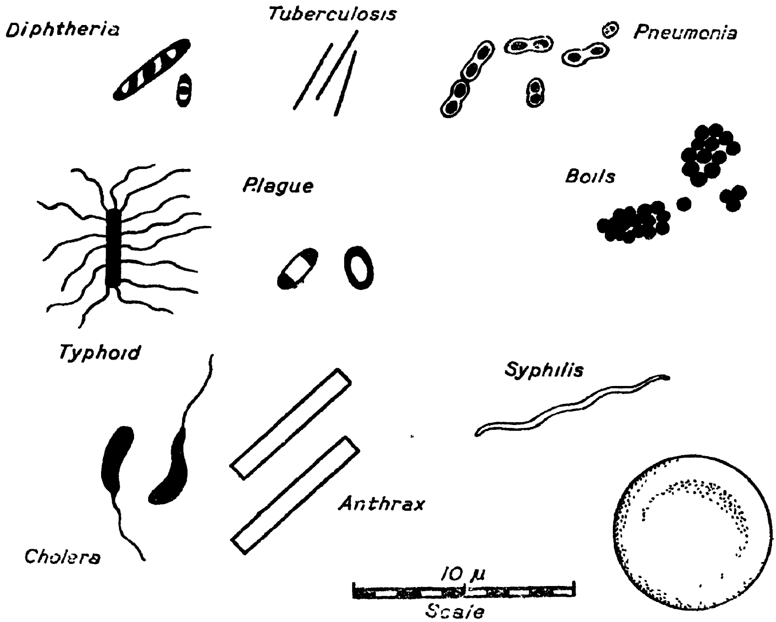

FIG. 103. SOME BACTERIA VIEWED THROUGH A MICROSCOPE

The bacteria shown are those responsible for certain diseases in man. A single human red corpuscle of blood has been drawn to the same scale for comparison.

(3) **The Spirillum** (L., *spirillum*, small coil). Corkscrew-shaped forms are called spirilla, or spirochætæ, and swim vigorously with a twisting motion.

Some bacteria do not clearly belong to any of the above groups, but wherever possible they are placed, for the sake of convenience, in the group to which they bear the most resemblance.

Bacteria feed on a variety of substances, different types favouring different foods. Thus we find some types living in the soil, others infecting the living bodies of animals, while others feed on dead organisms only. When bacteria have absorbed the chemical compounds which they require as food they convert them in their bodies and excrete any unwanted material.

Sometimes the chemical substances excreted by bacteria are poisonous to other living organisms, which is the reason why infection by bacteria may cause disease. In this way great numbers of diphtheria bacteria in the throat may produce poisons which will kill the infected person, whereas the many millions of lactic-acid bacteria which we drink in milk do not produce poisons, and therefore do not harm us. Any poisons produced by bacteria are called **toxins** (Gk., *toxikon*, a poison).

Fortunately, relatively few bacteria produce toxins, and so among the enormous numbers of bacteria to be found everywhere few are **pathogenic** (Gk., *pathos*, suffering; *genos*, offspring), or disease-producing.

Bacteria reproduce rapidly by splitting in half, each division occurring every twenty or thirty minutes under favourable conditions. A single bacterium might therefore give rise to about seventy-five billion offspring in twenty-four hours. Conditions, however, are rarely so favourable as to permit such rapid growth. Lack of food or the accumulation of the bacteria's excretory products limits reproduction.

When bacteria enter living organisms or reach some other material which can serve them as food they first go through a period of slow growth as they become accustomed to their surroundings. A period of very rapid growth then follows, but as the food becomes less or the bacteria poison themselves by their excretory products, or are attacked by the body's defences, they decline and die.

Some bacteria, however, do not die in unfavourable conditions, but pass into a resting stage. In order to do this they form a hard, resistant wall round their bodies, so becoming what are called **spores** (Gk., *sporos*, seed), and in this form they can withstand high temperatures which would kill them in their active state. Thus the spores of the anthrax bacillus will retain their vitality for at least fifteen years and withstand, when dry, temperatures of over 100° C., while the same bacillus in its active state is killed by temperatures greater than 50° C.

2. The Life of Louis Pasteur

The name of Louis Pasteur is especially remembered for his researches on bacteria, which laid the foundations for the science of bacteriology. Pasteur was born in 1822, in the town of Dôle,

France, and went to school in the town of Arbois, where his father owned a tannery. In 1838 he travelled to Paris, in order to enter the École Normale, but his health broke down, and he was forced to return. He went to study, however, at the college at Besançon, and there, at the age of eighteen, he was awarded the degree of Bachelor of Letters. For some years Pasteur taught at Besançon, and then he went to Paris once more to study at the École Normale. It is interesting to note that the examiner in his entrance examination to this institution observed that his chemistry was "mediocre" only.

In Paris Pasteur came under the influence of the two great chemists Dumas and Balard, who encouraged him to pursue his researches in chemistry. Pasteur therefore began the study of the crystalline structure of certain chemical compounds, and he made the important discovery that in the case of a variety of tartaric acid, racemic acid, and in various compounds, two crystalline forms exist, which he found differ only in their physical action, and which can be separated by a species of mould.

This employment of a living organism in chemical research led Pasteur to his classical discoveries on fermentation and decay, during which he discovered that fermentations do not occur in the absence of bacteria, yeasts, or certain other living organisms (p. 190).

Pasteur later applied his energies to the study of those bacteria which cause diseases in man and other animals. Pasteur found that, just as each fermentation is dependent on the presence of a particular organism, so also are many diseases dependent on the presence of particular bacteria.

In 1865 Pasteur was asked to investigate a disease which at that time was causing widespread destruction among the silkworms of Europe. After a great deal of patient work he identified the agents responsible for this disease, and suggested means for preventing its recurrence. These discoveries brought Pasteur fame and wealth, but he wished to continue his studies on fermentation, so in 1871 he returned to the study of fermentation with the object of improving the beers of France, and he spent some years on this work.

Eventually, however, Pasteur returned to the study of diseases, and made discoveries in this field which have made his name famous throughout the world. He first investigated the disease of anthrax, which at that time caused great mortality among

cattle and sheep. By employing the methods which he had used in his fermentation studies Pasteur was able to obtain pure cultures of the bacillus responsible for this disease, and so he gained a greater insight into the nature of the disease. Later he turned his attention to various diseases in man, including puerperal fever.

Pasteur's greatest work, however, was yet to come. In 1879, while working on the disease fowl cholera, he discovered a means of rendering birds immune to this disease, and later he extended the method to permit the immunization of sheep and cattle against anthrax. Finally the supreme test, that of immunizing a human being against disease, was made. In 1885 Pasteur and his helpers were investigating the disease of hydrophobia, which is given to man by the bite of a mad dog, when a young Alsatian boy named Joseph Meister travelled to Paris covered with wounds from the bites of a mad dog. Without treatment he would undoubtedly have died of hydrophobia, but Pasteur treated him by the method of inoculation which he had developed, and after some weeks it was clear that the boy would not develop the disease.

Pasteur died in 1895, after a lifetime spent on scientific research which had brought him great honours and financial rewards. He left behind as a memorial great discoveries in crystalline chemistry, fermentations, and disease, including the discovery of artificial immunity, which to-day protects mankind from so many diseases, against which previously no protective measures were possible.

3. Fermentation and Decay

The apparently spontaneous chemical changes by which milk will in time become sour are well known. Such **fermentations** are characteristic of a wide range of organic materials. In due course they lead to **decay,** and it is by such chemical reactions that the dead bodies of animals and plants are destroyed as such and converted into simpler chemical substances.

Formerly the processes of fermentation and decay were believed to be inevitable, self-regulated chemical changes in organic materials, until in 1857 **Louis Pasteur** (Plate 21) produced convincing proof that decay will only occur in the presence of minute living organisms, by whose activities chemical changes are brought about.

When milk is allowed to stand for some days a substance

called lactic acid is produced by the conversion of lactose, or milk sugar, according to the following reaction:

$$C_{12}H_{22}O_{11} + H_2O = 4\ CH_3.CH(OH).CO_2H.$$

Pasteur examined soured milk and found in it a great number of 'rod-shaped corpuscles,' which were later called bacteria. He transplanted some of these 'corpuscles' into solutions of pure sugar and ammonium salts and showed that their multiplication

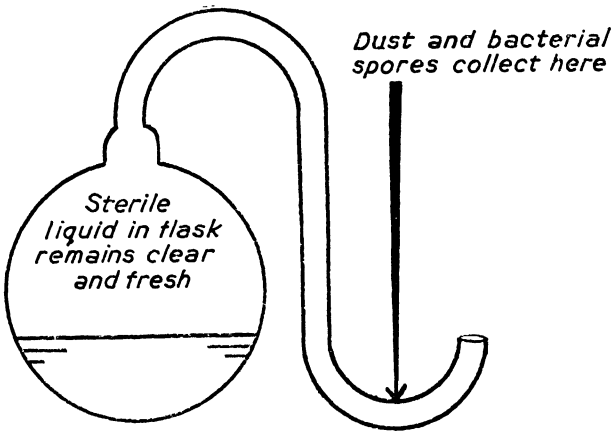

FIG. 104. ONE TYPE OF FLASK USED BY PASTEUR TO SHOW THAT PUTREFACTION WAS BROUGHT ABOUT BY THE ACTIVITY OF BACTERIA

was accompanied by the transformation of the sugar into lactic acid.

Subsequent researches showed that milk and other organic materials will not decay if they are first heated, in order to destroy any living organisms present, and then enclosed in such a way that no bacteria nor fungi can reach them (p. 190 and Fig. 104). This is the principle adopted so widely to-day in the canning of foodstuffs. Moreover, researches showed that particular species of bacteria brought about particular chemical changes. Thus, whereas lactic acid bacteria convert sugar into lactic acid, acetic acid bacteria convert sugar into acetic acid, or vinegar. The differences in the chemical changes are related to the differences in the metabolism of the various species.

To sum up, therefore, no fermentation or decay takes place without the agency of living organisms, and for every fermentation there is a particular organism.

Pasteur's work on fermentation had important practical

applications. If wine is heated at from 55° C. to 60° C. the activities of vinegar-forming and other bacteria are checked, and so the wine remains fresh, while its flavour does not suffer by the process. Milk is also treated in this way to destroy any dangerous bacteria in it, such as those which cause the disease of tuberculosis. The process of sterilization of wine and milk by gentle heating is called **Pasteurization** (see Plate 22).

4. Disease and Defence

Many diseases are caused by the toxins produced by bacteria. A list of some types is given below:

Bacilli	Spirilli
diphtheria	relapsing fever
typhoid	tick fever
tetanus (lockjaw)	syphilis
tuberculosis (Plate 23)	
bubonic plague	
Streptococci	**Staphylococci**
blood-poisoning	boils
pneumonia	pimples
cerebro-spinal fever	
scarlet fever	

Some persons are especially susceptible to disease, while others are rarely ill. We may look, therefore, for some explanation of immunity, choosing for our examples two diseases which attack young people.

(*a*) Diphtheria is a disease caused by the *Bacillus diphtheriæ*, which lodges in the throat and manufactures deadly toxins, which may even stop the beating of the heart and cause death.

(*b*) The spots, boils, and pimples which we most of us suffer from at one time or another are usually caused by staphylococci which settle in the skin at the base of a hair or sweat-gland. The toxins which they produce are generally localized, however, and are not dangerous.

When pathogenic bacteria enter the body they are attacked first by white blood corpuscles and later by chemical substances called **antibodies.** The white corpuscles, together with other cells which also devour bacteria, are called **phagocytes** (Gk., *phagein*, to eat; *kytos*, hollow) (Plate 9).

A remarkable sequence of events occurs when any irritant enters the body, whether it be a thorn, a poison, bacteria, or some other toxic matter. First, large numbers of white blood corpuscles and other phagocytes accumulate near the damaged tissues. Next, the blood-vessels, including the capillaries, dilate and allow the white corpuscles to pass through their walls, which enables them to reach the damaged tissue. The dilation of the blood-vessels is followed by an increase in the quantity of blood in that area and an escape of lymph from the vessels to the neighbouring tissues, which consequently appear red and swollen. Such a condition is known as **inflammation.** This inflammation is increased by warmth, and we therefore apply poultices or other hot fomentations to the inflamed area to hasten the release of phagocytes from the blood.

Meanwhile the white blood corpuscles, together with more phagocytes from other regions of the body, gather round whatever irritant has entered the body and attempt to devour it.

The blood now also prepares the chemical antibodies against the infection if it is caused by bacteria or viruses.

If the infection is localized and can be dealt with by the phagocytes and the antibodies, as in the case of a boil, the patient will merely feel pain in the affected area, while a yellow fluid called **pus,** containing phagocytes, lymph, and the irritant will probably escape through the skin in the later stages. However, if the infection is not localized nor kept under control, poisons will circulate in the blood, as is the case with diphtheria, and by interfering with the heat regulation centres in our bodies will cause a rise in our body temperature, a condition we call **fever.**

Our immunity to bacterial diseases will therefore depend on the readiness with which our bodies will form antibodies against any germ which enters.

Squeezing a deep boil or pimple in order to remove pus may damage near-by cells, and so defeat its object by allowing bacteria in the boil to spread into near-by tissues, which will cause even greater infection.

5. Antiseptic and Aseptic Methods: Lord Lister

Prior to the nineteenth century surgery was usually attended by great mortality. Anæsthetics had not yet been used to ensure unconsciousness of the patient, and the pain and shock of opera-

tions often proved fatal. Putrefaction and decay of the wound was then an even more general and more puzzling cause of death.

While Pasteur was investigating the causes of putrefaction and fermentation, a young English surgeon, Joseph Lister (1827–1912), impressed by Pasteur's theories of the relation of micro-organisms and disease, applied them to hospital practice.

Joseph Lister (Plate 20) was the son of a London wine merchant, who himself contributed much important work on lenses. In 1860 he became Professor of Surgery at Glasgow University, where he performed much valuable research work, of which the most notable was his discovery of antiseptics.

Impressed by the great mortality of surgery (45 per cent. of amputation cases died in those days), Lister noticed that those cases which healed were generally those that were free from putrefaction. Pasteur's work on fermentation suggested that wounds kept free from infection by micro-organisms would remain healthy, so Lister looked for some means to effect this. Pasteur's method of sterilization by heating was clearly inapplicable to wounds, and so Lister looked for chemical substances which would kill bacteria but would not damage the body's tissues. He found that treatment of the operating instruments and the wound with carbolic acid prevented putrefaction, since it killed the micro-organisms present and so aided healing.

Such chemicals, which kill bacteria but do not greatly damage delicate tissues, are called **antiseptics** (Gk., *anti*, against; *sepsis*, putrefaction).

In 1924 Professor (later Sir) Alexander Fleming, of London University, described the results of experiments which he had made to test the effect of carbolic acid and other antiseptics on bacteria and the human body. He found that antiseptics in general have a more destructive effect on white blood corpuscles than on bacteria; in fact, that the application of antiseptics to an already infected wound is more likely to have harmful than beneficial effects. The value of antiseptics would seem to be limited to the prevention of bacterial infection.

Surgery is to-day performed under **aseptic** conditions. All the instruments used are first heated to a high temperature to destroy bacteria, the surgeon and his assistants wear sterile clothing, and the operating theatre is kept scrupulously clean. In these ways the risk of any bacteria reaching the wounds of the patient is greatly reduced.

6. Artificial Immunity

While Pasteur was investigating the disease of chicken cholera he made a lucky mistake that was to have important consequences. He had found that a small drop of the cholera bacillus culture would kill any chicken if it were inoculated with the culture. But one day Pasteur accidentally inoculated a chicken with an old preparation of the bacillus which was not powerful enough to kill it. To his great surprise that chicken which had already received injections of the weakened bacilli was not killed by subsequent injections of the virulent bacilli.

Pasteur also inoculated some sheep with a culture of anthrax bacillus which had been overheated. These sheep only became mildly ill, and thereafter seemed immune from anthrax, since inoculations of virulent anthrax bacilli did not kill them. Pasteur therefore conceived the idea that animals might be made immune from diseases by first **inoculating** them with a weakened culture of the bacteria of the disease, which should be sufficient to cause the blood to form chemical antibodies which would persist.

Then, by a daring experiment, Pasteur proved that he could render a flock of sheep immune from anthrax by his method of inoculation. Subsequently this method was widely used, and in a short time the deaths from anthrax among sheep dropped from 20 per cent. to less than 1 per cent.

The immunity secured by inoculation now forms a preventive measure for many diseases (Plate 25). The two methods of inoculation employed may be illustrated by reference to the prevention of typhoid and of diphtheria.

If a person is visiting a country where the drainage is poor and the disease typhoid is common he is well advised to receive preventive inoculation against typhoid. In this case a number of dead typhoid bacilli (which can be killed by heating for fifteen minutes at 65° C.) would be injected into the blood; the chemical substances which they produce would only mildly affect the patient, yet they would stimulate the blood to produce antibodies which will persist for several years, thus preserving the patient from infection by living typhoid bacilli.

Diphtheria inoculation is now widely practised in Britain and elsewhere, and there is no doubt that it prevents much disease and death. As in the case of typhoid, a dead culture of the bacillus is inoculated, and causes the formation of antibodies

in the blood. Such inoculation of dead cultures, or **vaccines,** as they are called, confers **active immunity,** and is the method employed in the widespread preventive measures against diphtheria.

In contrast, the method of **passive immunity** against diphtheria is used to cure the disease, or to protect persons who are known to have been recently in contact with a case of diphtheria. In this case the antibodies needed for protection are not made by the blood of the patient, but are made by the blood of a horse.

A young and healthy horse is first inoculated with a vaccine of diphtheria germs and subsequently inoculated at intervals of a few days with doses of increasing virulence until it can resist inoculation of pure diphtheria toxin. About six litres of blood are then taken from the horse and the **serum** is extracted and purified. This serum contains the anti-toxin to the diphtheria toxin. When a carefully-estimated dose is injected into a human being it confers a passive immunity against diphtheria.

Inoculations to confer active or passive immunity against disease have been extended to provide protection against a great number of bacterial infections. In all cases the blood of the patient, or of an experimental animal, is made to produce antibodies against a particular species of bacteria. Sometimes inoculations are not easy nor suitable, and clearly it would be preferable if we could inject chemical compounds which would have a destructive action against any particular bacteria already present in the body.

7. Cure by Drugs

Until recent years the chemical treatment of diseases was almost entirely limited to the use of drugs which would lighten the symptoms of the disease and so help the body to make the best use of its natural defences. Recent discoveries, however, indicate that we may be entering a new phase, when bacteria will be killed in the body of the patient by the use of chemical substances produced in laboratories.

When Lister discovered that he could kill bacteria before they infected wounds and harmed the patient scientists started to dream of the day when they might be able to kill bacteria **inside** the bodies of infected persons. Recent discoveries have made part of that dream come true.

Modern **chemotherapy** (Gk., *Chemia*, Egypt; *therapeuō*, cure) has had its origin largely in the work of Ehrlich (1854–1915),

who conceived the idea that dyes and other chemical substances might show an affinity for bacteria without harming the tissues of a patient. With this end in view Ehrlich and his fellow workers searched for a compound which would kill the syphilis spirochæte in the blood without harm to the patient. They proceeded to carry out a systematic investigation of organic arsenical compounds which culminated in the discovery of arsenic compound 606, subsequently known as salvarsan, which still has a limited use.

In the 1930's chemists of the great German dye-firms working at Elberfeld tried the effects of certain dyes on bacteria and found that one red dye, subsequently marketed as Prontosil, had a destructive effect on the bacteria called streptococci but did not harm human tissues.

Domagk, the research worker who published an account of the discovery of Prontosil's action in 1935, was one of the first to benefit by the discovery. His daughter ran a needle into her hand and developed bad blood-poisoning. Just as she was becoming unconscious and her condition seemed hopeless, the new drug was tried, and cured her.

In 1935 Prontosil was tried in many countries, including England, where it was tested in Queen Charlotte's Hospital, London, on cases of puerperal (childbirth) fever. Before 1935 one-quarter of those women who caught this disease died; to-day the use of the new drugs has reduced the deaths from puerperal fever to less than one in twenty of the infected persons.

Subsequent research work has shown that the part of Prontosil which kills bacteria is a well-known organic chemical with the alarming name of paraminobenzenesulphonamide. Chemists have tested variations of this substance on many forms of bacteria, and new discoveries are still being made. One derivative, called **sulphapyridine,** or **M and B 693,** produced by the English firm of May and Baker, has saved countless lives during the past few years. For instance, in the middle years of the first Great War two out of every three cases of cerebro-spinal, or 'spotted,' fever were fatal; in the latter years of the second Great War four out of five patients recovered from this disease. Research work on the effects of variations of these chemical compounds on bacteria still continues, and we may expect that a large number of new healing drugs will soon be available to doctors.

Another recently developed discovery also induces new hope for the fight against disease. In 1929 Professor (later Sir) Alex-

ander Fleming published his accidental discovery that a fungus called *Penicillium notatum* (Plate 24) produces a chemical substance that will inhibit the growth of certain bacteria and eventually destroy them. Fleming made this discovery by noticing that this blue-green mould, which is closely related to that which grows on jam and other foodstuffs, had accidentally entered some cultures of staphylococci and checked their growth. Moreover, he found that an extract of the material on which the mould was growing could be injected into animals to destroy staphylococci in the blood without having any apparent ill-effects on the white corpuscles. Subsequent researches have revealed means of purifying this extract, which we call **Penicillin,** and have shown that it is in many respects more efficient as a germ-killer than is M and B 693. Although it has a very destructive action on many pathogenic bacteria, penicillin is without apparent ill-effects on the human body. For several years following its discovery it was difficult to produce, but it undoubtedly possesses all the characteristics of an important weapon in the fight against disease.

We stand on the threshold of discovery. Tuberculosis and many other diseases are as yet practically immune against drugs. However, the recent work on chemicals which kill bacteria in the patient's body suggests that we may be near the end of that stage in the fight against disease which began when Pasteur showed that certain bacteria cause disease and Lister applied this knowledge to medicine.

8. The Ultra-filterable Viruses

One method of separating bacteria from fluids—for example, blood—in which they may lie is to filter them by passing the fluid through a fine porcelain filter, which blocks the passage of bacteria. There are, however, certain disease-producing organisms which will pass through the finest porcelain filter; these are consequently known as **ultra-filterable** (L., *ultra*, beyond) **viruses,** and although they are so small that they cannot be seen by using the ordinary optical microscopes,[1] they are nevertheless very important because of the epidemic diseases which they cause. Influenza, the common cold, measles, mumps, chickenpox, and smallpox are all the result of virus infections.

[1] Viruses can be photographed through the new electron microscopes (see Plates 26 and 27).

The viruses (L., *virus*, poison) are very difficult to study because they are so small, and because in contrast to bacteria **viruses cannot reproduce outside the body of a living animal or plant,** and therefore cannot be 'cultured' on a suitable nutritious material, as can bacteria. Once the viruses become established inside a living body they reproduce as rapidly as do the bacteria.

Early workers expected that the viruses would be found to be single organisms, possibly possessing something of the structure and organization of the larger forms of life. However, fairly recent work suggests that viruses should not be thought of as individual organisms, but rather as amounts of chemical substances.

This most important advance in our knowledge of the viruses is due to the work of an American, W. M. Stanley, who in 1935 published the results of experiments on a virus which causes disease in the leaves of tobacco plants. Stanley, by a series of chemical reactions, extracted from a diseased plant a protein which he could obtain as a pure crystal, yet which appeared to have all the properties of the virus. When this protein crystal was implanted in a tobacco plant it brought about all the symptoms of a virus disease. Clearly the identification of a pure chemical substance with a virus, which exhibits many of the properties of living matter, is an important step towards our understanding of the barrier which separates living from non-living matter. Most of such work on viruses is still in the experimental stage, and we cannot yet form any definite conclusions.

There is no doubt, however, of the value of further research work on viruses. As a leading scientist has said, "It is abundantly evident that a proper understanding of virus diseases and viruses is essential for the future well-being of mankind." In order to illustrate this statement, let us consider the destructive power of viruses. The great influenza wave which swept the world in 1919 caused more deaths than occurred in the whole of the preceding War; eighteen thousand people died in London alone. Smallpox, before vaccination was introduced, is said to have killed nearly two million people in Russia during one year.

Viruses also attack man's crops and his domestic animals. It is estimated that nearly two million pounds' worth of damage is done annually to the potato crops in England and Wales, while the ravages of foot-and-mouth disease certainly cause millions of pounds' worth of damage in the world each year.

The control of viruses is less advanced than is the control of bacteria, owing to the fact that they were more recently discovered. The discovery that ferrets, hedgehogs, and mice are all susceptible to the human influenza virus may lead to some protective measures against influenza, but at present the fact that there are many species of influenza viruses which all cause similar types of influenza is a handicap to scientific work on this subject. In the control of dogs' distemper better results have been obtained. The mortality among fox-hounds from this disease has been lowered by inoculations from a minimum of 50 per cent. to a maximum of 20 per cent.

IMPORTANT DISEASES DUE TO VIRUSES

Man	Cattle
Common cold	Cow-pox
Influenza	Foot-and-mouth disease
Measles	
Mumps	**Dog**
Chicken-pox	Rabies
Smallpox	Distemper
Infantile paralysis	
Yellow fever	**Birds**
Typhus (agents may be given as bacteria) (Plate 27)	Fowl plague
	Fowl-pox

Plants

'Leaf-roll' of potato
'Mosaic' of tobacco
'Curly-top' of sugar-beet
'Yellows' of peach
'Spotted Wilt' of tomato

9. Vaccination

At one time the disfiguring and deadly disease called smallpox was widespread. The present control of this disease is due to the practice of vaccination.

This was introduced in 1798 by Edward Jenner (1749–1823), who was born in Gloucestershire. In the countryside where he lived there was a tradition that dairymaids who had caught a mild disease called cow-pox from their cows did not subsequently take smallpox.

Jenner performed his first **vaccination** (L., *vacca*, cow) on a country boy by rubbing some matter from the cow-pox sores of

a dairymaid into a cut on the boy's arm (1769). Two months later he inoculated the boy with pus from a case of smallpox. The boy did not contract the disease.

The reception of Jenner's discovery was characteristic of that awarded to innovations. A few people approved it, but many more attacked it violently. Napoleon I was perhaps Jenner's most enthusiastic supporter; he promptly ordered the vaccination of all his troops that had not had smallpox. Even to-day there are anti-vaccinationists who are more affected by the extremely rare unfavourable reactions of the body to vaccination than by the enormous total of human suffering spared by this method of immunity.

To-day the vaccine, which is rubbed into scratches in the arm, is a pure virus obtained from calves.

SUMMARY

(1) Minute living things called bacteria bring about the decay of organisms, fermentations, and disease.

(2) The chemical reactions which they cause are due to their metabolic processes.

(3) Disease-producing bacteria exert their effects by means of excretory materials called toxins.

(4) The animal body is protected against bacteria by white corpuscles and other phagocytes and by chemical antibodies.

(5) Bacteria can be killed by chemical substances called antiseptics, or by heat. Surgical operations under conditions free from bacteria is called aseptic surgery.

(6) Immunity to bacterial and virus diseases is achieved artificially by inoculations.

(7) Some chemical substances produced in the laboratory kill certain bacteria, but do not harm the body.

(8) Ultra-filterable viruses, which are organisms smaller than bacteria, cause diseases in animals and plants.

SUGGESTIONS FOR HOME STUDY

(1) Distinguish between (*a*) natural immunity, (*b*) active immunity, and (*c*) passive immunity, the two last being artificially produced. Give examples.

(2) Write short notes on (*a*) fermentation, (*b*) decay, (*c*) aseptic surgery, (*d*) antiseptics, (*e*) penicillin.

(3) What happens when disease-producing bacteria enter the body?

CHAPTER XXI

PROTOZOA AND ALGÆ

A little one shall become a thousand.
Isaiah, lx, 22

1. Free-living 'Cells'

The bodies of most animals and plants are built of numerous units called cells, but there are also some organisms whose minute bodies appear to be composed of one cell only. Some of these living organisms live in soil, the sea, or fresh water, while others inhabit the bodies of animals.

Many of these **unicellular organisms,** as they are called, feed as plants do, by photosynthesis; others feed like animals on the living or dead bodies of other organisms. Botanists call the plant-like forms **algæ** (L., *alga*, seaweed) and include them in the phylum Thallophyta; zoologists call the animal-like types **protozoa** (Gk., *protos*, first; *zoon*, animal). In our survey of these organisms we may avoid the difficulties of estimating the value of this classification by referring all these types to one group, the unicellular organisms.

A unicellular organism usually has a body consisting of a mass of protoplasm, which contains a nucleus and is bounded by a cell-wall. In these respects it resembles a body-cell in higher animals or plants, but differs from the latter in the varied functions which the cytoplasm may perform. Often certain portions of the cytoplasm are specialized to perform one function. For example, some of these organisms move by the action of vibrating 'hairs,' or whip-like lashes, on their bodies; some have eye-spots to guide them to light; a few even form shells to protect their bodies.

Most unicellular organisms live freely in sea and fresh water, where they are found in very considerable numbers. If we were to leave a glass jar, containing some pond or river water, in sunlight for a week or so we should find that the sides of the jar would become coated with a green slime, and that the water also became green. In both cases the colouration is due to the presence of innumerable plant-like unicellular organisms. We should also find protozoa, which would be present in still greater numbers

jugare, to yoke) often occurs, during which two paramecia fuse, and later divide to form eight new individuals (see Plate 16).

Paramecium preserves a regular 'slipper' shape by means of a stiff cell-wall, and is therefore sometimes called 'the slipper-animalcule.'

Euglena viridis. **Euglena** is another unicellular organism found in ponds. Euglena is much smaller than Amœba or Paramecium, and can only be seen with difficulty under the low power of the microscope. However, it can easily be recognized by its jerky motion through the water, which is in contrast to the smooth movement of Paramecium. It moves by the beating of a single long whip-like lash called a **flagellum** (L., *flagellum*, whip).

Euglena usually feeds like a plant, by the aid of chlorophyll, and has an orange eye-spot to guide it to the best position for obtaining light for photosynthesis to occur.

Euglena reproduces like Amœba, by simple division. Occasionally Euglena may lose its chlorophyll and feed in a manner more like an animal, by absorbing organic matter. For this and other reasons, therefore, Euglena is generally included by zoologists in the phylum Protozoa, while botanists place it in the phylum Thallophyta.

Chlamydomonas. This organism resembles Euglena in many respects, but it is almost spherical and it moves by the beating of two flagella.

Protococcus. Protococcus is an example of a unicellular plant which differs from most other unicellular types in its ability to live out of water. The green, powdery coating often seen on trees, fences, and rocks is composed of many individuals of the genus Protococcus. Protococcus contains chlorophyll, and feeds like a plant by means of photosynthesis.

Shells and Capsules in Protozoa. Some protozoa form shells, capsules, or spicules, which strengthen their bodies. Where these forms occur in very great numbers, their remains often form considerable deposits. The marine protozoa belonging to the orders Foraminifera and Radiolaria are especially important in this respect. The skeleton of a member of the order Foraminifera often consists of a perforated shell through which fine cytoplasmic processes project (see Fig. 107). Members of the order Radiolaria each form a skeleton, which consists of a central capsule, often strengthened by spicules. Members of these two orders often occur in very great numbers in the sea, and the

skeletons left by dead individuals may contribute to the formation of ocean-floor deposits. Chalk very largely consists of the skeletons of long-dead Foraminifera or Radiolaria.

2. Malaria

Few European travellers to the East escape malaria.[1] This disease is characterized by a sudden fever, which rises to a climax

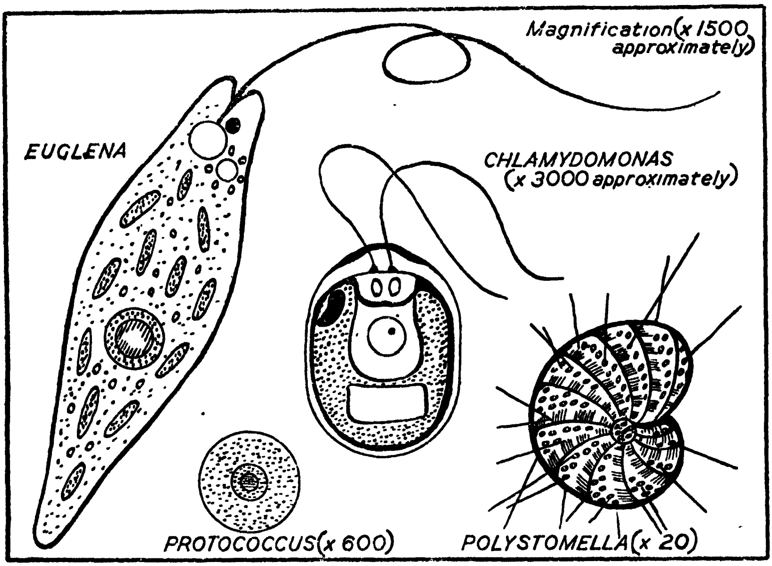

Fig. 107. Some Single-celled Organisms
These figures are diagrammatic. Polystomella belongs to the order Foraminifera.

every three or four days until the victim either conquers it or dies. Even if a sufferer from malaria recovers from the disease the organism responsible for it may still remain in his blood and bring on other attacks after a period of some months or even years has elapsed.

A unicellular organism called **Plasmodium** is responsible for the disease malaria and lives on the red blood-corpuscles of man, producing poisons which may kill the host. Organisms which live thus on other living things are called **parasites.** In England cases of parasitism are fortunately rare, owing to the clean con-

[1] Malaria is now rare in the British Isles, though in past centuries it was a fairly common disease.

ditions of life and the low temperature which do not favour the parasite. In tropical climates, however, parasites are a serious problem. Single-celled organisms and parasitic worms undermine the health of the populations, both European and native.

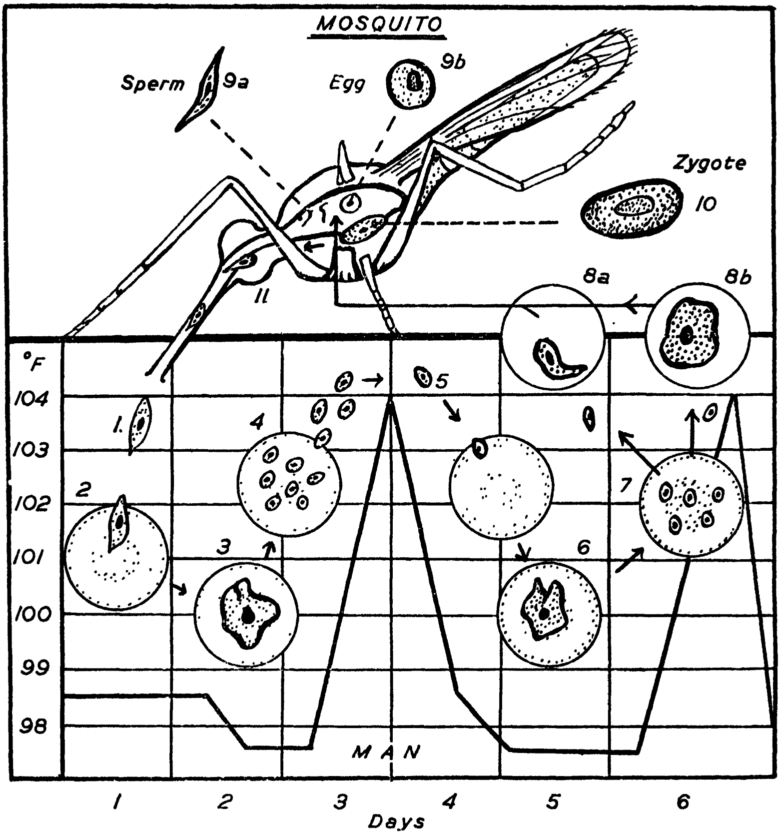

FIG. 108. DIAGRAMMATIC LIFE-HISTORY OF THE MALARIAL PARASITE, PLASMODIUM VIVAX

In the upper figure an anopheline mosquito is shown in the act of 'biting' a man. The body walls have been opened to show the contents of the stomach, and the mouth parts are enlarged. In the lower figure stages in the life-history of Plasmodium are shown in relation to blood-corpuscles, and they are superimposed on the temperature chart of the patient.

The malarial parasite, like most other parasites, has a complicated life-history (Fig. 108). It spends its life in two host animals, man and the mosquito. We may begin our study of the life of the malarial parasite at the moment when it enters a man by the bite of a mosquito.

As a female mosquito of the genus **anopheles** bites a man and sucks in his blood, her saliva, which often contains many malarial parasites, may enter the wound and infect the blood-stream. The single cells of the malarial parasite (1) find their way to blood corpuscles, which they enter (2). The malarial organism then divides many times inside the blood-corpuscle (3, 4), and the new individuals so formed are liberated into the blood plasma, together with poisons (5), causing an immediate rise in the temperature of the patient. In one species, *Plasmodium vivax*, the products of division are released after three days, causing what is known as 'tertian ague' (L., *tertius*, third). Other species, *P. falciparum* and *P. malariæ*, release their products of division every four days, or after an indeterminate period, respectively.

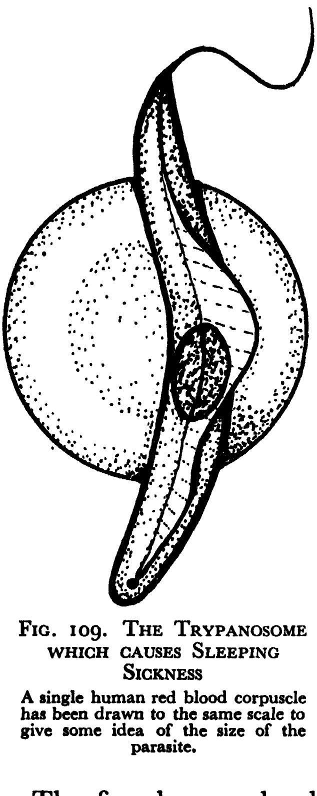

FIG. 109. THE TRYPANOSOME WHICH CAUSES SLEEPING SICKNESS

A single human red blood corpuscle has been drawn to the same scale to give some idea of the size of the parasite.

This rapid reproduction may continue until billions of blood-corpuscles contain malarial parasites and the patient is very ill. After some time, however, the asexually reproducing forms develop into sexual forms (6, 7), which can only continue their life-history if the infected man is bitten by a mosquito. If this happens the sexual forms pass into the stomach of the mosquito, and there form eggs and sperms.

The female sexual cell (8*b*) forms one egg (9*b*). The male sexual cell (8*a*) forms a number of sperms (9*a*). One sperm fertilizes one egg, and the resultant zygote (10) wriggles into the stomach-wall, where it becomes enclosed in a capsule. The protoplasm of the zygote divides inside this capsule to form a number of elongated cells, which migrate to the salivary glands of the mosquito (11) and remain there, to be injected in the saliva when the infected mosquito bites another man.[1]

[1] The methods by which the spread of malaria is checked are discussed in a later section (pp. 264–267).

3. Sleeping Sickness

Another disease caused by a unicellular parasite renders large areas of Africa uninhabitable. This disease, called **sleeping sickness,** is caused by a parasite known as a **trypanosome;** these trypanosomes are carried from one host to another by the **tsetse-fly,** in which some stages of this parasite's life-history are passed. Trypanosomes infect insects, plants, and most animals in Africa without causing much damage to their hosts. In man and his domestic animals, however, some species infect the spinal cord and brain, and bring about loss of consciousness and death. The future of Africa may largely depend on the successful control of the tsetse-fly, for at present certain regions of Central Africa cannot be entered by man or his stock without great danger.

SUMMARY

(1) There are many minute living organisms which have bodies that are apparently composed of one cell only. Some of these feed as plants do, while others are clearly animals by their methods of feeding. Others of these unicellular organisms live as parasites in the bodies of other living organisms.

(2) The malarial parasite and trypanosomes are economically important types. This conclusion arises from a discussion of their influence on mankind.

SUGGESTION FOR HOME STUDY

In what ways do Amœba, Euglena, and the malarial parasite (*a*) resemble, and (*b*) differ from, a typical animal or plant cell, and from each other?

on which the fungus is living, where it absorbs organic matter over all its surface.

Mucor, when growing on the surface of jam, absorbs glucose in solution, together with oxygen from the air, and performs normal **aerobic** (Gk., *aer*, air) respiration, so releasing carbon dioxide, water, and free energy. In the deeper layers of the jam the mycelium of some species of Mucor may respire **anaerobic-**

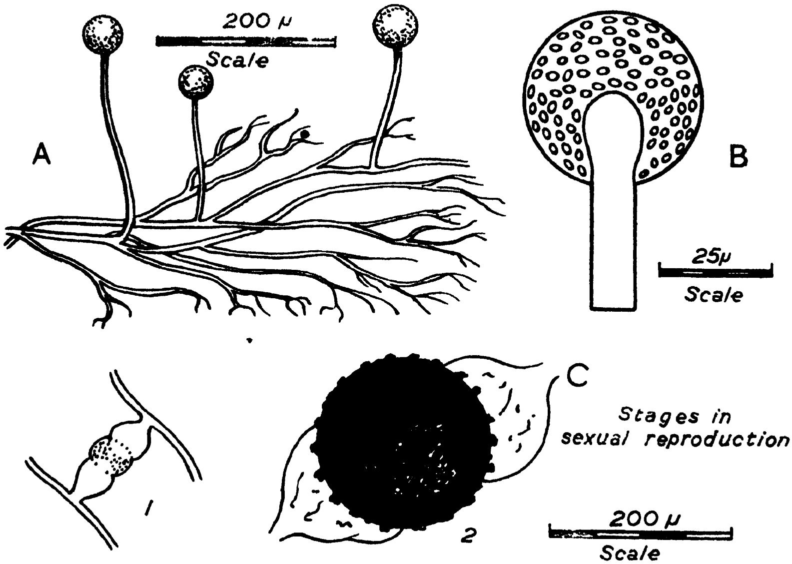

FIG. 110. DIAGRAMS TO ILLUSTRATE THE LIFE-HISTORY OF MUCOR

A, a small portion of a mycelium, bearing three erect Sporangiophores; *B*, a section through a single sporangium; *C*1, an early stage in the fusion of two gametangia; *C*2, the mature thick-walled Zygospore.

ally (*i.e.*, without air), and if this is the case the glucose is converted into carbon dioxide and alcohol. We sometimes notice the taste and smell of alcohol in jams which have been fermented by the respiratory activities of Mucor.

Researches on the subject of another mould, called *Aspergillus niger*, have shown that when this fungus is not growing, or is growing very little, the amount of heat and of carbon dioxide given off is such that we may reasonably suppose that almost all the glucose which is being respired is completely broken down to carbon dioxide and water, and that the free energy is being dissipated as heat. However, when the mould is growing we find that the heat released is many times greater than we might expect from the amount of carbon dioxide liberated. Moreover, the

amount of carbon dioxide liberated is less than we might expect to be produced from a complete respiration of all the glucose absorbed by the fungus. In fact, the interpretation of these results suggests that an important aspect of respiration in fungi is the formation of compounds, intermediate between sugar and the final products of respiration, which may serve to build the body of the fungus.

After a certain period of growth Mucor develops reproductive organs, which are of two main types.

Asexual reproduction. The commonest method of reproduction in Mucor, as in most fungi, is by the production in great numbers of single cells, called **spores,** which are small enough to be scattered by the wind, and can withstand a certain amount of dryness or change of temperature; when one of these settles on any food material it will germinate to form a new mycelium.

The reproductive process is as follows. Upright hyphæ grow above the food material and bear spore-cases on their tips. Each aerial hypha, which is known as a **sporangiophore,** becomes swollen at its apex and densely filled with protoplasm. A cross-wall separates the apex from the rest of the sporangiophore, and within this apex, called a **sporangium,** the spores develop. As many as a hundred spores may form in each sporangium. The sporangia and sporangiophores resemble pins in appearance, and give Mucor the name of 'the pin-mould.'

A projection called the **columella** (L., *columella,* small column) extends into the sporangium from the sporangiophore, and eventually contributes to the bursting of the sporangium wall and the liberation of the spores, which are borne away by the air.

When the spores settle on a suitable food material they germinate within a few hours, each spore giving rise to a new mycelium.

Sexual reproduction. Asexual reproduction is in fungi generally found associated with a plentiful supply of food, for when food becomes scarce they reproduce sexually. The process of normal spore formation involves no nuclear behaviour beyond nuclear division, and is therefore termed asexual, whereas in another type of spore formation, practised by Mucor, the formation of a resistant spore is preceded by the fusion of nuclei, and is therefore regarded as a sexual process.

The sexual reproduction of Mucor begins with a process called **conjugation.** Two near-by hyphæ approach one another, and their tips meet. These tips, which are called **gametangia**

(Gk., *gametes*, husband; *angeion*, vessel), become cut off from the mycelium by the formation of cross-walls. Each gametangium is filled with protoplasm, which contains many nuclei. Eventually the walls between the two gametangia break down, and the nuclei from both fuse together in pairs.

When the nuclear fusion has taken place the whole structure develops a greatly thickened dark wall, and is called a **zygospore,** which is very resistant and remains dormant for several months. When, under suitable conditions it germinates, it gives rise directly to a sporangiophore and sporangium, and the asexual reproduction of the fungus immediately begins again.

Mucor lives principally on non-living organic matter, and therefore does little direct harm to other living organisms, although it may give rise to economic loss by contaminating food; many fungi, however, live as parasites on the bodies of plants, which consequently become diseased. Some of these, such as the potato-blight fungus, grow on man's crops, and produce serious economic effects.

2. The Potato-blight

Potato-blight is a widespread disease which usually appears in Britain about the end of July and is first observed on the leaves of the plant. These lose their green colour and become spotted with yellow patches, which soon turn black. Around the margin of each black patch is a border of white, which resembles fine flour.

In damp weather the fungus causing the disease spreads rapidly from plant to plant, and, after destroying the leaves, attacks the stem, and may in a few hours reduce the whole potato plant to a foul-smelling, decomposing mass of debris.

Potato-blight is caused by the attacks of a fungus called *Phytophthora infestans*. The mycelium of the fungus permeates the tissues of the leaves and stems, and feeds on them parasitically. In damp weather branched hyphæ grow outward through the leaf surface, usually making their way through stomata. Small oval spores, called **conidia,** are borne on the tips of these branched aerial hyphæ. The conidia are light, and are spread by the wind. When they alight on other potato plants they will continue their development if they can find a film of dew or rain-water. Each conidium divides, forming between six and sixteen active cells,

which are called **zoospores.** These can swim by the action of two hairs called cilia, but they soon come to rest and develop a long tube, which penetrates the leaf of the plant and, once it is imbedded in the leaf-tissues, forms a new mycelium.

The life-history of the blight fungus is incompletely known,

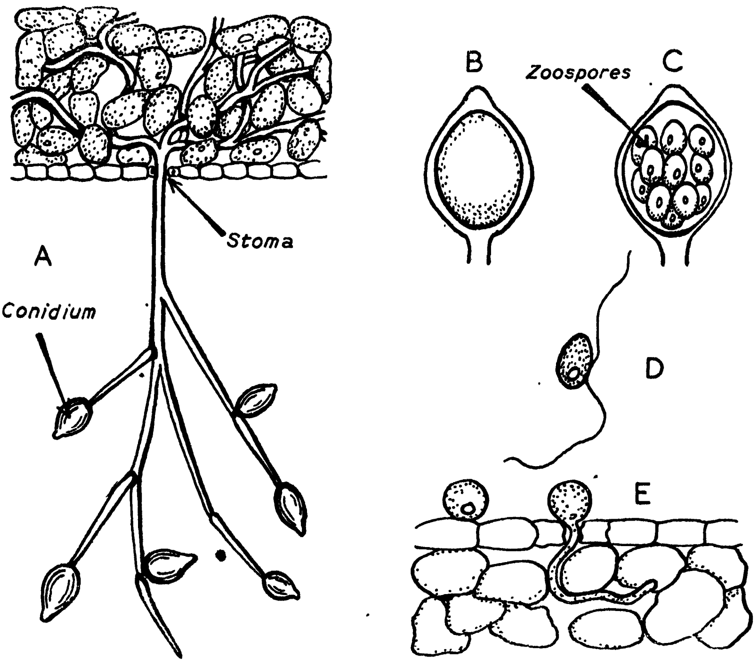

FIG. 111. LIFE-HISTORY OF PHYTOPHTHORA INFESTANS, THE POTATO-BLIGHT
A, a branched hypha, bearing conidia, projecting from the lower surface of a leaf; *B* and *C*, successive stages in the formation of zocspores within a conidium; *D*, a single zoospore, which in *E* is shown entering a leaf through a stoma.

and we do not yet know certainly how the fungus survives the winter.

3. THE MUSHROOM

The mushroom, together with its near relations, the toadstools, is found in fields, woods, and other places, and is a fungus resembling Mucor in many respects. Mushrooms and some toadstools can be eaten, but since many toadstools contain deadly poisons the distinguishing of the edible varieties should be left to the expert.

Agaricus campestris, the common mushroom, lives in the soils of grass pastures, especially when these are well manured. The

mycelium of the fungus grows beneath the surface, and it is only the reproductive bodies that are normally used for food. The hyphæ are branched and many-celled, and are woven together to form strands. When the mushroom has reached a certain size reproductive organs form. Each of these fructifications consist of a thick stalk (the **stipe**), supporting an umbrella-like expansion (the **pileus**), on the underside of which there are a

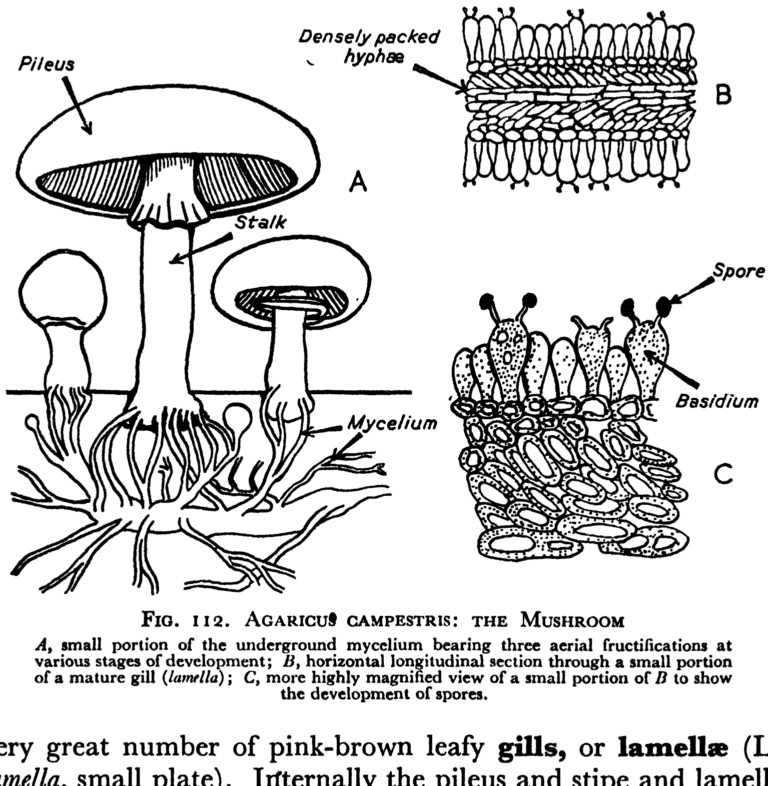

FIG. 112. AGARICUS CAMPESTRIS: THE MUSHROOM

A, small portion of the underground mycelium bearing three aerial fructifications at various stages of development; *B*, horizontal longitudinal section through a small portion of a mature gill (*lamella*); *C*, more highly magnified view of a small portion of *B* to show the development of spores.

very great number of pink-brown leafy **gills,** or **lamellæ** (L., *lamella*, small plate). Internally the pileus and stipe and lamellæ are built up of densely packed hyphæ.

A very great number of spores are produced on the surfaces of the lamellæ. Cells called **basidia** (L., from Gk., *basidion*, small base), which are separated by sterile cells, form the surface layer. Each basidium possesses in its early stage two nuclei, which later fuse; the fused nucleus then proceeds to divide twice. The resulting nuclei pass into the two **basidiospores** produced by each basidium. The basidiospores are wind-borne; under suitable conditions each germinates to form a new mycelium.

In many essentials the mushroom resembles Mucor. Like most fungi both are saprophytes and have a body consisting of a mycelium of hyphæ; both reproduce asexually by means of spores. Points of difference are apparent in the details of spore formation, however, while, with the possible exception of the fusion of nuclei in the basidium, there is no sign of any sexual process in the mushroom. The hyphæ also differ in structure,

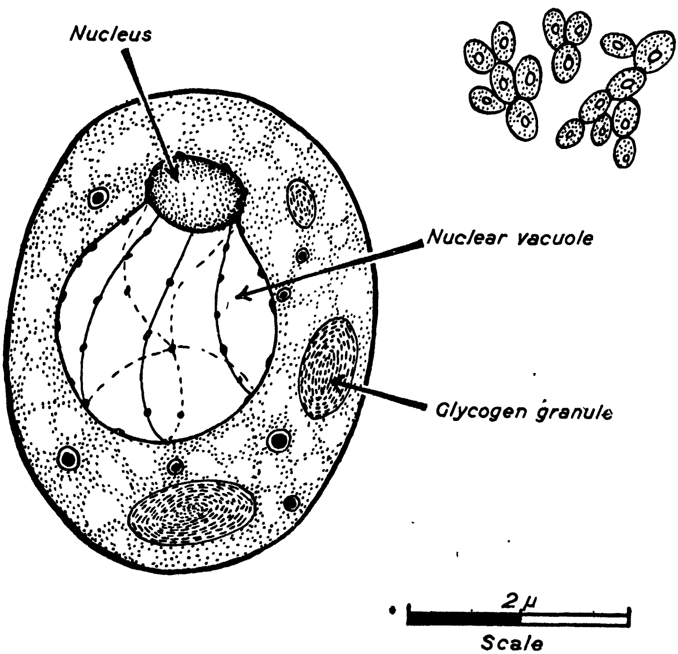

FIG. 113. YEAST

A single individual, highly magnified, and a small portion of a colony to show budding.

those of Mucor being continuous, while those of Agaricus are divided into many cells.

4. YEAST

If you should enter a bakery or brewery and ask for yeast you would be handed a curiously-smelling substance, in appearance not unlike rubber or cheese and with about the same consistency as the latter. Take a piece of this home with you and examine it under the microscope. Its living nature becomes more apparent.

Yeast is a fungus belonging to the genus Saccharomyces. The

yeast which we obtain from a brewery is nothing more than millions of living individuals, each of which is oval in shape and possesses a nucleus, which lies near a peculiar-looking cavity called a nuclear vacuole. There is little in the appearance of yeast to suggest that it could be useful to man, yet every year countless yeast-cells all over the world help mankind in the processes of bread-making, wine-making, and the brewing of beer.

The peculiar property of yeast which makes it so useful to man is its method of respiration. It usually does not breathe in the same manner as do the majority of living things, for while, like animals and plants, it respires sugars to give energy, it accomplishes this process *without the use of oxygen.* This type of respiration is called **anaerobic.** It is effected by means of the action of enzymes, a group known collectively as **zymase** being responsible in this case. The products of this reaction also differ from the products of our respiration. They are not carbon dioxide and water, but carbon dioxide and alcohol. Here is the basic chemical equation for this process:

$$\underset{\text{(glucose)}}{C_6H_{12}O_6} \rightarrow \underset{\text{(ethyl alcohol)}}{2C_2H_5OH} + \underset{\text{(carbon dioxide)}}{2CO_2}$$

The respiration of yeast may therefore be used as a cheap and easy method of manufacturing alcohol from sugar; yeast is invaluable to us for the manufacture of wines, beers, and spirits.

The Making of Beer. There are two essential chemical processes involved in the brewing of beer. The first is the conversion of the starch found in certain cereals into **maltose** and other sugars. The second is the **fermentation** of these sugars with the aid of yeast to form alcohol.

In practice it is found that barley is the most suitable cereal to use in the manufacture of beer, although maize, rice, oats, and wheat could also be used. Brewing is accomplished in a number of stages.

Stage 1: *Malting.* If barley is moistened and kept for some hours at 10–18° C. it begins to germinate. When this occurs a number of chemical reactions take place in the grain, including the conversion of starch into maltose and other sugars by the activities of the enzymes called **diastase.** In beer-making, therefore, barley is first moistened and warmed, so that germination begins. The germinating barley is called the **malt.**

Stage 2: *Kilning, or Drying.* When a certain stage in germination

has been reached the malt is then dried and roasted in a kiln at a temperature which is at first about 32° C. and which rises gradually up to 93° C. Malt for pale ales is roasted at about 68° C., while malt for dark beers is roasted at the higher temperatures. When the malt has been dried and roasted it may be stored or used at once in the next stage.

Stage 3: Mashing. The malt is next crushed and mixed with

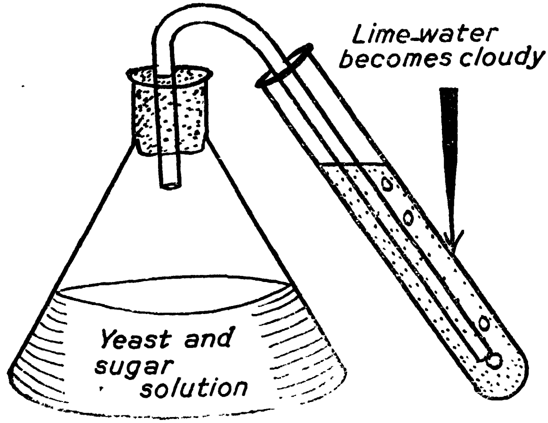

Fig. 114. Experiment to show that Yeast gives off Carbon Dioxide as it respires

hot water (about 74° C.) in a mashing vat. The diastase now acts powerfully on any remaining starch, converting it into sugars.

The liquid which now contains these sugars, in addition to some other chemical substances, is called the **wort.** The next procedure is to drain it off into large kettles, where it is boiled with **hops.** These flowers of the hop plant are added in order to impart a slightly bitter flavour to the beer, and also because they sterilize the wort by killing any bacteria in it.

Stage 4: Fermentation (Plate 28). After the wort has been boiled it is cooled to about 15° C., and then run off into vats, where yeast is added. By this time a great deal of the maltose has been converted into glucose by the action of an enzyme called **maltase,** which is present in germinating seeds. Yeast, by means of the enzyme **zymase,** respires anaerobically, and so converts some of the glucose sugar into alochol. Fermentation, together with the formation of alcohol, proceeds most rapidly under conditions of oxygen shortage. Yet under these conditions the activity of the cells diminishes, and they cease to bud and

grow. Conditions of aeration must therefore be adjusted carefully to permit growth, while not greatly inhibiting alcohol formation. Fermentation is carefully controlled, and when a certain stage is reached the yeast is separated, and the remaining fluid, which is now beer, is allowed to stand for a little while and is then bottled or placed in casks.

As we have previously noted, three main chemical processes are involved in the making of beer. During malting and mashing starch is converted into maltase sugar according to the equation:

$$\underset{\text{(starch)}}{2C_6H_{10}O_5} + H_2O \rightarrow \underset{\text{(maltose sugar)}}{C_{12}H_{22}O_{11}}$$

Maltose becomes converted into glucose, prior to fermentation, by the action of the enzyme maltase which is present in germinating seeds:

$$\underset{\text{(maltose)}}{C_{12}H_{22}O_{11}} + H_2O \rightarrow \underset{\text{(glucose)}}{2C_6H_{12}O_6}$$

During fermentation the glucose becomes converted into alcohol:

$$\underset{\text{(glucose}}{C_6H_{12}O_6} \rightarrow \underset{\text{(ethyl alcohol)}}{2C_2H_5OH} + \underset{\text{(carbon dioxide)}}{2CO_2}$$

The nature of the water used has an important bearing on the type of the resultant beer. Burton (Staffs.) is famed for its pale ales, while London and Dublin are noted for their stouts and porters. Burton water contains much calcium sulphate, while London and Dublin waters are softer, and bear more easily removed salts.

Bread-making. Certain varieties of yeast are used by bakers to cause their bread to 'rise.' In the process flour, salt, yeast, and water are mixed together, and kneaded into a thick paste, or dough. The whole mixture is then kept warm. The yeast is thereby kept under conditions favourable for fermentation, and so it forms a little alcohol, which probably escapes during baking, while great quantities of carbon dioxide are liberated, and form small cavities in the dough, thus making the bread less solid, and therefore more palatable. Eventually the loaf is baked in an oven.

Wine-making. Most fruits have wild yeasts growing on them, feeding on the sugar of the fruit. Apples are used for cider-making. The apple juice is squeezed from the fruit by a cider-press and then fermented by wild yeasts to form cider.

Red and white wines are made from purple or green grapes respectively, the process being similar to that described above.

Other Uses of Yeast. Yeast contains relatively large quantities of the vitamin B_2, and is therefore often used as a tonic.

Recent researches on the food-value of yeast suggest that some yeasts may be cultivated to produce valuable food proteins to supplement those meat proteins in our diet which are costly and difficult to produce.

5. Fungi in General

It has only been possible to consider here a few representatives of the Fungi, and many important groups have been left entirely untouched. Yet our study of the four selected types—Mucor, the blight fungus, the mushroom, and yeast—permits us to make a general survey of the activities of this important group.

In their capacity as saprophytes they cause decay to occur in dead organisms, and so help to destroy the remains of dead plants and animals, which would otherwise accumulate so greatly as to interfere with living things. Fungi and other saprophytes cause dead matter to decay, and ultimately convert its materials into inorganic salts, which are available for plant food.

Many diseases of plants are due to the activities of parasitic fungi. For instance, wheat-rust, potato-blight, apple-scab, the damping off of seedlings, and the coffee disease of Ceylon are examples, to name but a few. Artificially cultivated crops seem very liable to attacks by fungi.

In animals diseases caused by fungi are fairly uncommon, but ordinary '**ringworm**' and **tinea cruris** (ringworm of the thighs) are two examples in man. Many fish and other aquatic animals are susceptible to a fungus called Saprolegnia, which gathers on any wound and eventually may kill the animal. Goldfish and other fish in bowls or aquaria often die because this white fungus clogs their gills and stops their breathing.

The chemical activities of yeast are utilized for the fermentation of wines and beers, while mushrooms and some other fungi are eaten as food.

Certain chemical compounds derived from fungi are valuable in the laboratory and in medicine (see Chapter XX, p. 220).

Analysis of Two Typical English Beers compared with that of Four Lager Beers[1]

	Alcohol Percentage by Weight	Reducing Sugars (calculated as Maltose Percentage)	Non-reducing Sugars (calculated as Dextrin Percentage)	Nitrogenous Matter as Protein Percentage	Mineral Matter Percentage	Acid (Lactic) Percentage	CO_2 Percentage	Original Gravity
Bottled pale ale	3·7–4·8	0·7–2·0	1·0–3·5	0·33–0·5	0·3	0·13–0·16	0·4	55°
Draught mild ale	3·3–3·5	0·6–1·5	1·0–2·0	0·24–0·32	0·25	0·11–0·13	0·22	42°
Lager	3·34	0·99	2·07	0·28	0·14	0·22	0·39	44°
Pilsener lager	3·54	—	—	0·42	—	—	—	49°
Light lager	3·30	1·46	2·02	0·35	0·17	0·24	0·38	44°
Munich lager	3·58	0·74	4·91	0·50	0·23	—	—	54°

[1] These details have been kindly supplied by Usher's Brewery, Trowbridge, Wilts.

SUMMARY

(1) Fungi have bodies and methods of reproduction not unlike those of plants, but they feed on organic matter like some animals.

(2) Some, like Mucor, feed on decaying matter; others, like the potato-blight, are parasites on living plants.

(3) Yeast is a fungus which converts sugar into alcohol. It is therefore used in the making of beer and wines.

(4) Many fungi are thus found to be economically important, some doing a great deal of damage while others are extremely useful.

SUGGESTIONS FOR HOME STUDY

(1) Compare the structure and the lives of Mucor and Phytophthora (potato-blight).

(2) Discuss the economic importance of fungi, giving examples of their influence.

CHAPTER XXIII
LIVING TOGETHER

Everything that lives,
Lives not alone, nor for itself.
W. Blake, *Book of Thel*

Some species of animals and plants live together in especially close relationships. In some cases individuals called **parasites** (Gk., *para*, beside; *sitos*, food) live on—or in—the living bodies of other organisms; a few organisms of different species live together for their mutual benefit, a condition called **symbiosis** (Gk., *syn*, together; *bios*, life). Some animal species form highly organized social **communities.**

1. Parasites

When two species live together but only one partner derives benefit from the relationship the condition is called **parasitism.**

The **mistletoe** provides an example of a plant parasite. Mistletoe plants possess chlorophyll, but they obtain water and salts from the trees on which they grow instead of from the soil. The fruit of the mistletoe is said to attract the missel thrush, which eats the food material but wipes the seed off its beak on to the bark of a tree.[1] As the seed germinates it sends rootlets through the bark into the tissues. Mistletoe is to be found on poplars, apple-trees, oaks, and other trees.

As examples of animal parasites we may consider the **nematodes,** or 'round-worms,' which are widespread in animals and plants. Some species of these animals are able to exist apart from other organisms; a spadeful of garden soil contains millions of nematodes. Others live in the intestines of man and other animals, where they usually do little harm unless they are present in too great numbers. About fifty species have been found living in mankind, but only a few of these cause serious diseases. It is not uncommon to find these fine, thread-like white worms in the fæces, and should not be cause for alarm.

Some species seem to inhabit particular regions only. One species has rarely been found outside the appendix of man;

[1] Some authorities disagree with this popular belief.

another has been found only in the felt mats on which Germans set their mugs of beer.

Some other parasites which live in or on the living bodies of other animals or plants have been considered elsewhere. These are potato-blight (p.235), malarial parasite (p. 228), ichneumon fly (p. 261), trypanosomes (p. 231), saprolegnia (p. 243).

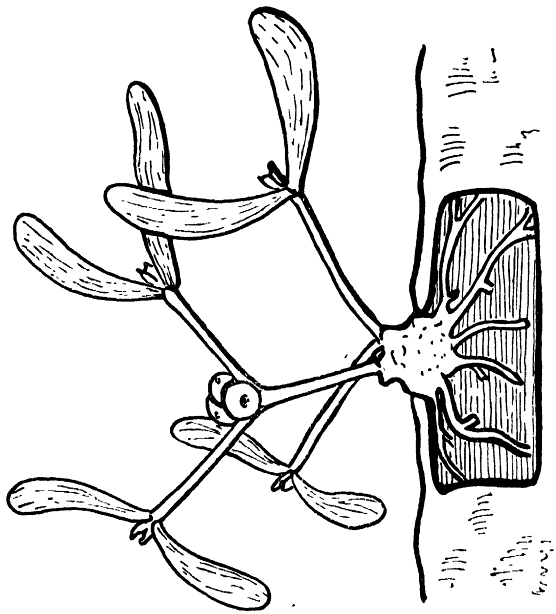

FIG. 115. MISTLETOE PLANT GROWING ON A BRANCH
A small portion of bark has been removed to show the rootlets of the mistletoe.

2. SYMBIOSIS

Organisms which are linked together for their mutual benefit are said to live together in a symbiotic relationship. The hermit crab and the sea-anemone are two organisms which often are found living together in this way.[1] The hermit crab is a creature with a soft body, which it covers by living in the empty shell of a whelk or some other mollusc. On this borrowed shell the crab may place a sea-anemone, which it then carries about on its travels. The crab benefits by this arrangement because the sea-anemone helps to camouflage it, and thus, by rendering it

[1] Some authorities prefer to consider this as a case of 'commensalism,' and to reserve the term symbiosis for yet closer relationships.

inconspicuous, protects it from its enemies. The sea-anemone, by the aid of its power of stinging, may also help the crab to defend itself. In return for this the anemone is carried to good feeding areas and probably picks up many particles of food left by the crab.

A more complete case of symbiosis has already been considered in the chapter on plant nutrition (Chapter VI). The root-bacteria which form nodules on the roots of peas, beans, and clover derive benefit from this association because they feed on the carbohydrates in the root-tissues. In return they allow the plant to make use of some of the nitrogenous matter which they have been able to build up from the nitrogen of the atmosphere.

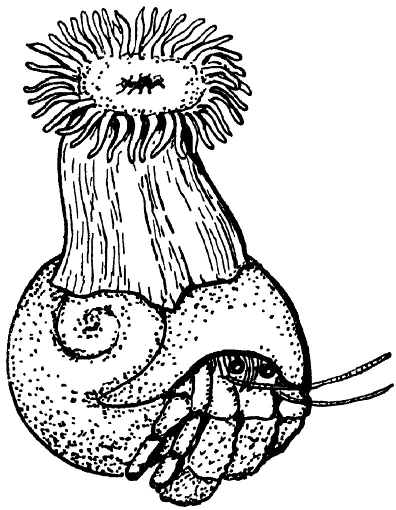

FIG. 116. HERMIT CRAB IN THE SHELL OF A MOLLUSC WHICH BEARS AN ANEMONE

Some biologists consider this to be a case of symbiosis, while others prefer to regard it as a looser association, which they call 'commensalism' ('mess-mates').

3. BEES

Sometimes many individuals of the same species will live together and co-operate for the benefit of the whole community. A most striking example of an animal community is provided by the 'social' insects. Here individuals carry on constant selfless labour for the good of the species. A variety of instinctive reactions enable the individuals to perform the many and varied tasks of community life.

Wasps, bees, ants, and the white 'ants,' or termites, all contain species which live social lives; but that of the bee is the most important for human beings, since bees convert the nectar they collect as food for their young into honey, which is also used by man as food. Men have kept bees in artificial hives for two thousand years or more.

Bees in the wild state make their nests in the hollows of trees, or in other sheltered places. Such nests are not convenient for man, since he cannot easily extract the honey. Bee-keepers therefore keep bees in wooden hives, which contain detachable

frames on which the bees build honeycombs to fill with honey. When their work is complete the bee-keeper removes the frame and replaces it by a fresh one, on which the bees store more honey.

The Inhabitants of the Hive. There is a remarkable division of labour in the beehive. There are three different types of bee, each serving a different function (Plate 29). The appearance and function of these types is summarized below.

The Queen. The queen is the female founder of the community. There is usually only one queen in each hive. She is specialized for reproduction and is able to lay between two and three thousand eggs in twenty-four hours. Her average length of life is from two to three years. She has a long, tapering body and short wings, while her sting, which is large and sabre-shaped, is employed only in battles with rival queens. The queen has no apparatus for collecting pollen, while her mouth-parts are too short to reach the nectar in most flowers; she is therefore dependent on the workers of the hive for her food.

The Drone. This is the male bee. The drone is large, with well-developed eyes and great wings which make a loud humming noise when he is in flight. He has no sting, neither has he any apparatus for collecting pollen. He is essential for the fertilization of the queen's eggs, but apart from this function plays little part in the hive—spending his days sunning himself, and often feeding on the nectar collected by the busy workers. The drones are born in the spring and are slaughtered by the workers before the autumn.

Workers. The workers are females, but only very rarely do they have the power of reproduction. They develop from eggs which have been laid in small compartments, and from larvæ fed with only a moderate amount of food; if an egg which would normally form a worker is removed by the bees to a larger compartment and the larva is fed on better food its reproductive organs will develop and it will eventually become a queen.

Workers are smaller than queens or drones; they have a short body but long wings. Their mouth-parts are long, in order to collect nectar, while they have very hairy hind legs for collecting pollen and a small sac, called a **pollen-basket,** on each hind-leg, in which it may be carried. Workers have barbed stings with which they protect themselves.

The workers build the hive, stock it with honey and pollen,

care for the developing eggs, feed the larvæ, and regulate the temperature of the hive by fanning with their wings to cool it, or by clustering in dense batches for warmth. They usually live for about six weeks in the summer, but if they are born in the autumn they will live until the following spring.

The Hive throughout the Seasons. Bees cannot find nectar during the winter because there are few winter flowers.

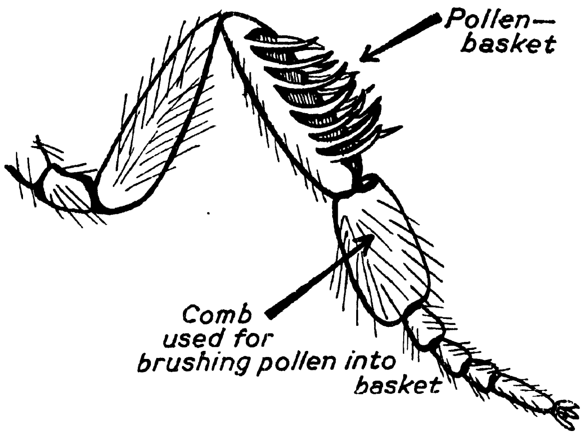

FIG. 117. HIND-LIMB OF A WORKER BEE

The weather is cold, and the bees cluster round the queen in a dense mass, trying to keep warm by the gentle beating of their wings. Honey, accumulated during the previous summer, is used by the bees for food.

As the spring comes the hive begins to stir. Some workers begin to build new combs, others venture out in search of water and nectar. The queen rouses herself and starts to fill empty cells in the honeycomb with the fertilized eggs which she has retained in her body throughout the winter.

The workers build the hive, or 'honeycomb,' with wax, which they manufacture in their bodies from the nectar collected from flowers. The comb is made up of many thousands of elongated, six-sided cells, which are used for the storage of honey or as brood-cells; in the latter case the cells are small, medium, or large in size, according to whether they are to receive worker eggs, drone eggs, or queen eggs.

The sex of each egg is determined before the queen lays it. All her eggs are potentially male and can undergo development

without fertilization (this process is called **parthenogenesis**), but if they have been previously fertilized by sperms they become females. The queen carries the sperms from the drone with which she mated and fertilizes an egg she lays in a worker or queen cell, but lays the eggs in drone cells unfertilized. The distinction between workers and queens is effected as the larvæ are fed.

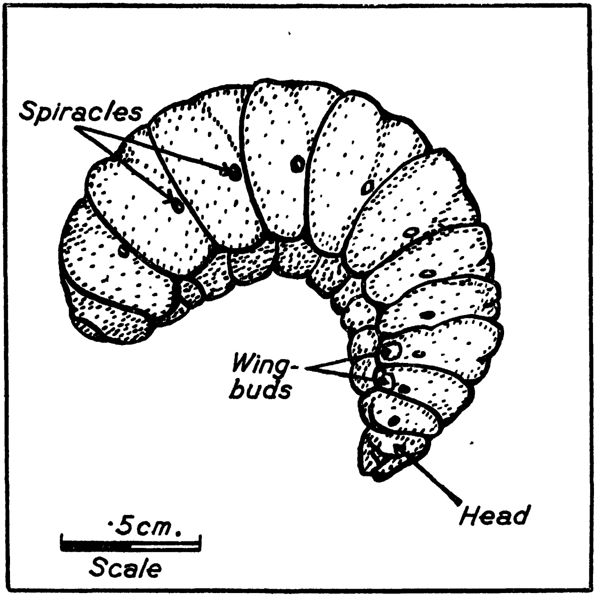

FIG. 118. LARVA OF A HONEY BEE

Queen larvæ are fed on a specially nutritious jelly, which is called 'royal pap,' while workers receive poorer food. Queens develop from worker eggs if the larvæ are fed on royal pap.

Eggs are laid in the brood-cells by the queen and the developing larvæ are fed by the workers. As is the case with many other insects, the egg becomes a larva and later a pupa. Sixteen days after the eggs have been laid the young queens emerge; twenty-two days is the time of development in the case of workers; twenty-five days are needed for the formation of drones.

Clearly the birth of many new bees will lead to overcrowding in the hive, and in such a case the queen and some of the workers will decide to leave the hive and to found a new hive elsewhere. One day the queen, instead of laying eggs as usual, will become restless, and move about, infecting the workers with her un-

easiness. Soon the latter will rush in a **swarm** out of the hive, followed by the queen. The dense cloud of bees will fly about seeking some place where a new nest may be built. Unless the swarm is captured by a bee-keeper and placed in an artificial hive, it may settle in the hollow of a tree, or some other place where its honey is inaccessible to the bee-owner.

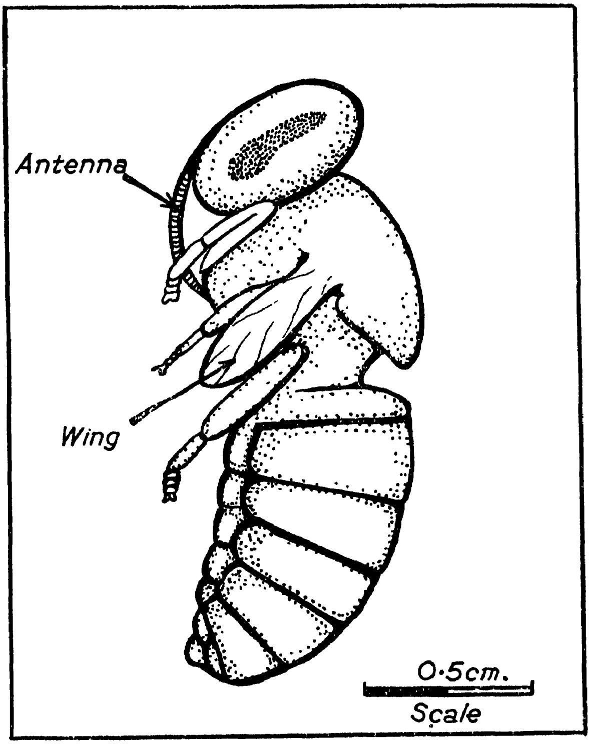

FIG. 119. PUPA OF A WORKER BEE, VIEWED FROM THE LEFT SIDE

The original hive will have now been left with only a few workers to care for the developing eggs. Soon, however, these develop, and the first adult to emerge is a young queen. She may lead many of the workers in a secondary swarm or she may remain in the hive. If she decides to remain in the hive she must first contend with any other queens which may develop, because only one queen may reign in a hive. The first young queen to emerge will, if she can, sting her young sisters to death before they emerge from their royal brood-cells. Generally, however, the workers

restrain the first young queen from doing this, and a battle may later develop between rival queens for the control of the hive. Queens are well suited for battle because of their large stings, which are curved like sabres.

The workers emerge from their brood-cells soon after the queens, and set about the collection of honey and the repair of the hive; later the drones appear, nine days after the emergence of the queens.

Five to seven days after her birth, the young queen leaves the hive to go on her **marriage,** or **nuptial, flight.** She rises higher and higher into the air, pursued by those drones left by the previous colony in the hive and by some drones from near-by hives. As the queen ascends some of the drones can fly no farther and stop the pursuit. Finally, only one drone is left, but he, poor fellow, gains a poor reward for his exertions, for the act of mating is violent. The queen rips the reproductive organs from the successful drone and leaves the husk of his body to flutter to the ground. She then returns to the hive with the male reproductive organs, which she will use to fertilize some of her eggs as they are laid. After her return to the hive the queen does not leave it until she leads a new swarm.

The return of the queen from her nuptial flight is the signal for a renewed burst of activity in the hive. Some workers build **brood-cells,** in which the queen lays her eggs; others build cells for the storage of honey.

When the eggs are laid and the honey is stored the bees may again swarm away to find a site for a new hive. The number of swarms in a year from any hive depends on the speed with which the hive can be provided with honey, which is in its turn dependent on the amount of food available for the bees in the locality.

Bee-keeping. A bee-keeper maintains bees in an artificial hive from which the honey that they make can be easily removed. If possible, swarming is prevented by the careful removal of honey, ventilation of the hive, and the removal of queens. However, swarms often occur, and it is then the aim of the bee-keeper to capture the swarm and to place it in a new hive before it can escape and found a new home in some inaccessible place.

The early swarms are liked best by the bee-keeper because they soon settle down and produce honey; the late swarms cannot lay

up sufficient food for themselves for the winter and may need to be fed with sugar. Hence the popular saying:

A swarm of bees in May
Is worth a load of hay;
A swarm of bees in June
Is worth a silver spoon;
A swarm of bees in July
Is not worth a fly.

During winter months bees must be kept warm, and may need to be fed with sugar by the bee-keeper.

4. Ants

The ants have a social organization that is curiously like our own social life. Not only do they live in communities like the bees, but they also fight wars, keep domestic animals, and cultivate fungus gardens!

Like the bee-hive, the ant-nest contains three main types of individual: one or more queens, short-lived fertile males, and sterile workers (Plate 29). The sexual forms are winged, the workers wingless. In the summer the winged males and females leave the nest for their nuptial flight, during which mating occurs. The fertilized females found new colonies, either alone or with the help of any workers which they may gather.

The nests of ants are excavated and constructed from soil. In Britain these nests are small, but in tropical countries the nests of ants and of the termites, or white 'ants,' may be fifteen feet high.

Food is seldom stored by ants, but is generally eaten at once. The type of food consumed varies according to the species of ant; in some it is other insects, in others juices or seeds of plants, in others again fungi.

A division of the labour among the workers has been accompanied by the evolution of various types. Thus, in some species we find soldiers, builders, nurses, and others that merely 'tend the flocks.' The domestic animals of ants are **greenflies,** or **aphides.** These insects exude from their bodies a sweet fluid called **honey-dew** which is eagerly sucked by the ants. Some workers, which are known as **repletes,** serve as honey-pots for their fellows by absorbing great amounts of honey-dew into their distended stomachs, from this supply later feeding their more active companions!

Another group, the leaf-cutting ants, carry home leaves and grow fungi on them in much the same way that we make artificial mushroom beds. These gardens are carefully tended, and provide food for the community.

Occasionally ants fight with neighbouring communities, usually with the object of obtaining slaves. Members of a British species (*Formica sanguinea*) fight another species, capture their larvæ, and bring them home to rear as slaves.

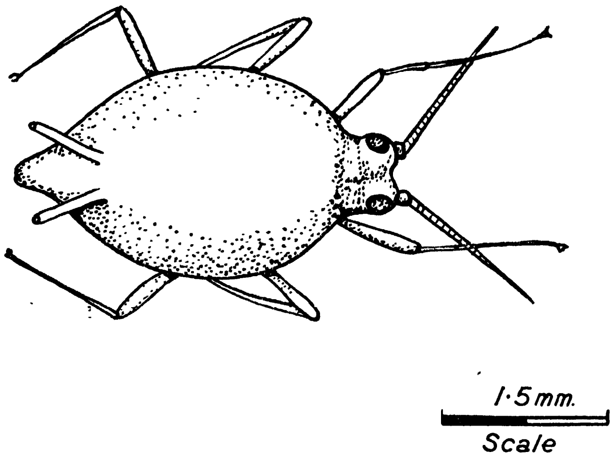

FIG. 120. GREEN-FLY, APHIS SAMBUCI

This type of green-fly supplies 'honey-dew' to ants. The figure is redrawn after Buckton.

5. Social Life in Animals and Man

Man is a social animal, and it is tempting, though perhaps unwise, to compare the social life of man with that of insects. Unwise, because one must realize that man and insects differ in one very important respect. All our evidence shows that the activities of insects are governed by blind instinct, while man differs from other animals in his ability to reason.

Many social reformers have pointed to the successful and stable insect colonies as the ideal social life, but it is to be doubted whether such a social life would be possible, or even desirable, for man. For, above all, man's behaviour is governed by reason, with accompanying ambition and prejudices.

Insect colonies have attained such a well-organized form that little change appears to have taken place for many millions of years, a time which has sufficed for man to evolve from simpler

animals. A complete stability in the social life of man might abolish the striving of the species, and thereby arrest the evolution of man.

SUMMARY

(1) Parasites are organisms which derive their food from the living bodies of other creatures.

(2) Certain individuals of different species often live together in close association. When this association benefits both parties it is called symbiosis.

(3) Ants and bees live social lives, and the individual effort is organized for the good of the community.

SUGGESTIONS FOR HOME STUDY

(1) What is a parasite? Give a number of examples.

(2) Discuss the food of bees and ants, indicating how feeding may influence insect colonies.

(3) Describe an insect community and compare it to (*a*) a human community, (*b*) a single animal body.

CHAPTER XXIV
BIOLOGICAL CONTROL

So, naturalists observe, a flea
Hath smaller fleas that on him prey;
And these have smaller fleas to bite 'em,
And so proceed *ad infinitum*.

J. SWIFT, *On Poetry*

1. BIOLOGICAL CONTROL

LIVING organisms compete with one another for food, and in this way influence each other's lives. As an example of this interdependence, it will be realized that if one animal depends on another for its food any increase in the numbers of the predator will diminish the numbers of the prey. This interdependence of living organisms forms a delicate interlocking balance.

The great naturalist Charles Darwin illustrated this balance by his discovery that in any village district the number of cats indirectly affects the number of clover plants in the fields.

The explanation is as follows. The ovules of clover must be fertilized by the pollen from another clover flower if they are to develop. Bumble-bees collect this pollen and use it to feed their young; during this process they carry pollen from one flower to another and deposit some near the ovules. Many of the bees are destroyed, however, by field-mice, which eat the young bees while they are still in the brood-cells. Fortunately for the clover, the field-mice are eaten by cats, and therefore the more cats there are in the neighbourhood, the less mice, the more bees, and the more clover!

Animals and plants are inextricably woven together in the web of life because animals are ultimately dependent for their energy on the sun's rays; this energy is available to animals in the form of the chemical substances built up by plants. The biblical statement that "All flesh is grass" bears some truth. We, for example, may eat rabbits, but the rabbit has fed mainly on grass. The frog may eat insects, but those insects depended on trees or smaller plants for their food. A company of animals which only ate animal flesh could not survive, for eventually only one animal would remain, which would look in vain for another to devour.

Sometimes men have by ignorance of the balance of nature

upset it, to their great disadvantage. When, in the fifteenth century, the Portuguese landed on the island of St Helena they brought goats, which promptly began to eat the undergrowth of the forest. After some years all the young trees were destroyed, and the luxuriant vegetation finally disappeared; the fertile soil, no longer bound by the roots of trees, was swept by the wind and the rain into the sea, leaving the rock naked.

Men sometimes deliberately upset nature's balance for their own purposes, and they sometimes find that unexpected results occur. Jamaican sugar-canes were at one time attacked by a plague of rats, which landed from ships and found that an unlimited supply of sugar and a pleasant climate made for a very agreeable life. So perfect were the conditions that the rats multiplied at an alarming rate, and the islanders, who could no longer keep them down by the usual means, decided to import the Indian mongoose. These animals, whose appetite for rats, snakes, and other unappetizing food is famous, soon diminished the numbers of rats, but increased in numbers themselves. Eventually there were not enough rats left to feed the mongooses, who turned their attention to lizards, snakes, and birds' eggs. These animals keep in check the insects, which otherwise would multiply so greatly as to destroy the crops. Thus the whole balance of life on the island of Jamaica was violently disturbed in the space of twenty years, and it was not until man had devised a method for checking the number of mongooses that a new balance of life was attained.

However, modern biological knowledge now enables us to avoid many such mistakes, and, moreover, to influence deliberately the balance of nature, in order to destroy pests.

2. The Case of the Prickly-pear

When a plant is removed from a region where it is under a natural biological control by its enemies to a region where the normal checks to its spread do not exist it multiplies very rapidly. The spread of the prickly-pear plant in Australia, and the method of its subsequent control, provides a striking illustration of the biological control of an organism which is undergoing excessive multiplication in abnormal surroundings.

Opuntia inermis and *Opuntia stricta* are two species of the family Cactaceæ which normally flourish in North and South America,

being adapted to a dry, hot climate. The fleshy stems of the plants contain much water, and the leaves are modified to form spiky projections. In America their spread is checked by a number of insects which feed on them. Their covering of spines generally deters larger animals from eating them, but they are sometimes used as forage plants or for hedging purposes.

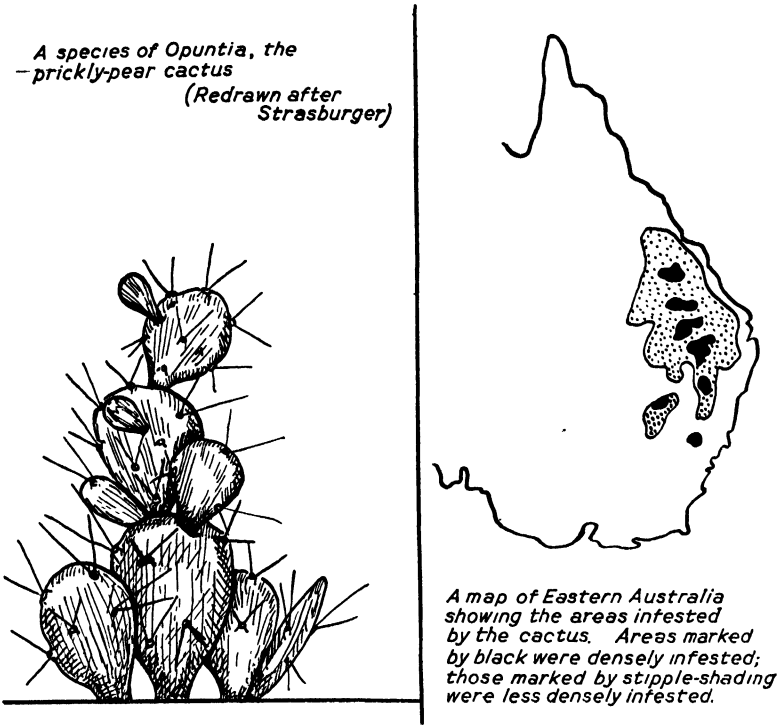

FIG. 121. THE PRICKLY-PEAR CACTUS IN AUSTRALIA

In 1839 *Opuntia inermis* was brought to New South Wales by a settler, and in 1860 *Opuntia stricta* arrived. Soon these plants escaped from cultivation and began to get beyond control: From 1900 onward the spread became very rapid, and by 1925 about fifty million acres in Queensland and ten million acres in New South Wales were affected. The dense growth of cactus choked all grass and herbage, and made the land unusable. A number of species were involved, but *O. inermis* and *O. stricta* were the chief pests.

There appeared to be no natural checks to their spread, and

so scientists were sent to America to search for any organisms there which fed on, and destroyed, cactus plants. About 150 species of insects and of other parasites of cacti were found. Some of these would not thrive in Australia; others were unsuitable because they did not restrict their attacks to cacti but fed also on other plants. However, a number of moths, bugs, beetles, and spiders were brought to Australia.

One insect, the moth-borer (*Cactoblastis cactorum*) proved to be especially fitted for the task, and by 1927 this insect had become firmly established. Some three thousand million insects were released between 1928 and 1930, and in a few years vast areas of prickly-pear were reduced to a decaying pulp. As the pear became reduced in numbers the consequent lack of food diminished the population of Cactoblastis, and there was therefore an alarming revival in the growth of pear between 1931 and 1933. However, Cactoblastis soon took charge again, and by 1934 the areas were again under control. To-day 95 per cent. of the area previously covered by Opuntias is free once more.

The moth-borer, *Cactoblastis cactorum*, is a native of the Argentine and Uruguay. The female moth lays between a hundred and three hundred eggs, which hatch into larvæ. These then burrow into the cactus plant and feed on it. The damage which they do allows bacteria and other infective organisms to enter, and so the cactus is destroyed.

3. The Cabbage White Butterfly

For our second example of biological control we may consider an insect the larva of which feeds on vegetables, but which, fortunately for man, has an enemy by means of which its spread can be controlled.

Those butterflies which are known as 'cabbage whites' are common in English gardens, where they are considered to be pests, since the larvæ feed on the leaves of cabbages and other vegetables (brussels sprouts, radishes, turnips, etc.). The common cabbage white butterflies belong to the genus Pieris of the family Pieridæ. There are three common species, which are distinguished by their size and markings. The large white (*Pieris brassicæ*) has a wing-span of 60–76 mm. The small white (*P. rapæ*) has a wing-span of 40–58 mm. *P. Napi*, the 'green-veined white,' resembles *P. rapæ*, but has more conspicuous venation on the wings.

All are common, but the life-history of the large white only will be discussed here.

Eggs are laid by the adult butterfly in the spring or late summer on the under-surface of a leaf at the rate of about four a minute, and from these eggs there form, in seven days, larvæ called **caterpillars** (L., *catta*, cat; *pilosus*, hairy). These caterpillars, which are worm-like in appearance, with a body divided into thirteen segments, some of which bear legs or claspers, emerge

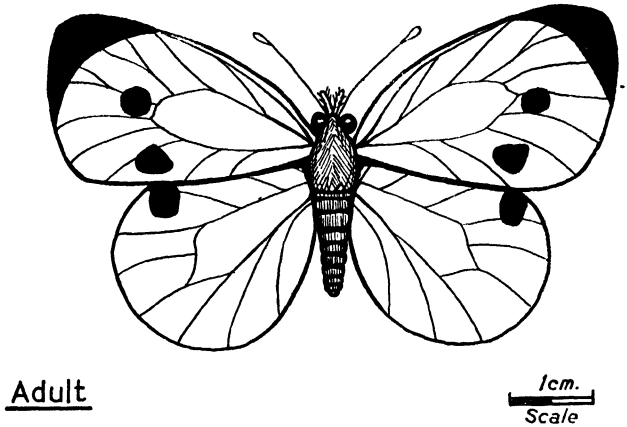

FIG. 122. ADULT FEMALE OF THE CABBAGE WHITE BUTTERFLY, PIERIS BRASSICÆ
Drawn from a specimen.

from their egg-shells, which they then devour. Later they feed on cabbage leaves, which they bite with powerful jaws. Their perception of their surroundings is helped by a number of simple eyes in their heads and by two sensitive hair-like projections called **antennæ** (L., *antenna*, sail-yard). Breathing takes place through minute holes in the skin, called **spiracles.** The caterpillar possesses silk-glands in its head which produce a fluid that hardens when dry to form silk. (The 'silkworm,' whose product makes true silk, is the larva of a related insect, the silkworm moth.)

As the caterpillar grows it frequently sheds its skin, since this is not elastic and would prevent growth. Active growth occurs between the shedding of one skin and the formation of a new one. After a number of such moults the animal spins a small pad of silk, from which it then hangs, and also a single thread of silk to serve as a girdle. After this activity has been completed, the larva undergoes a metamorphosis, or change, into a resting

pupa, or **chrysalis,** with a tough skin, inside which the larva passes through a series of changes while the adult organs are formed. The wings, eyes, antennæ, and feeding apparatus of the adult may be seen through the skin of the pupa.

Eventually the adult is fully formed, and it emerges through a slit in the upper surface of the pupal case. In the summer the

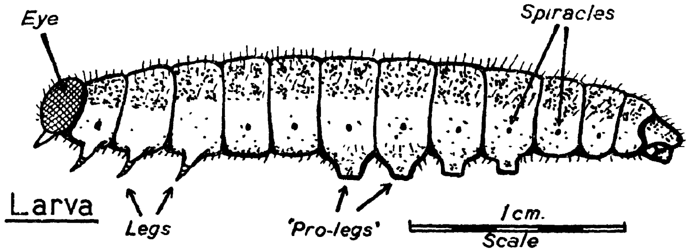

FIG. 123. LARVA, OR CATERPILLAR, OF CABBAGE WHITE BUTTERFLY, P. BRASSICÆ
This figure is drawn from a living specimen.

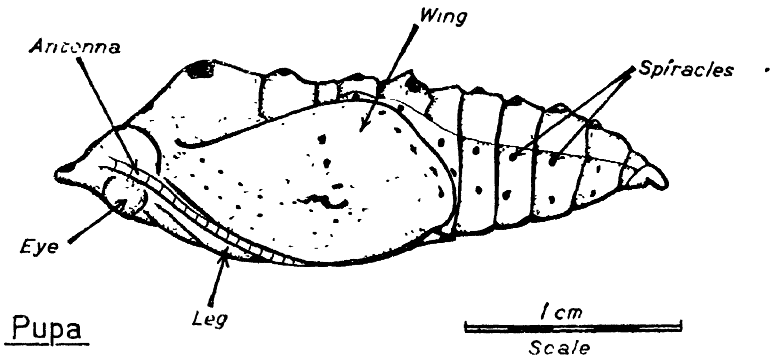

FIG. 124. PUPA OF THE CABBAGE WHITE BUTTERFLY, P. BRASSICÆ
This figure is drawn from a living specimen

pupal stage may only last for one or two weeks, but autumn pupæ developed from summer eggs remain dormant until the following spring.

Every year swarms of large whites invade this country from the Continent. Fortunately, their numbers are kept down by a small insect belonging to the order Hymenoptera (*Apanteles glomeratus*), which lays its eggs on caterpillars. Apanteles, which belongs to a family of insects called ichneumon flies, has a long egg-laying tube which can pierce the skin of the caterpillar. The eggs are laid in the latter's body, and later develop to form larvæ

which feed on the caterpillar and finally kill it. Man also attacks caterpillars by spraying plants with preparations containing some powerful insect-killer.

The small white butterfly was unknown in the New World before 1860, when a specimen was captured at Quebec, but by 1880 it had spread all over the United States east of the river Mississippi. There appeared to be no natural enemies to check its spread, but in 1883 the ichneumon apanteles was introduced, and helped to control its numbers.

4. Resistant Potatoes

The story of the potato-blight[1] before its control is a tragic tale of suffering. Potatoes form the main article of food for many peasants, and the disease which killed them in the last century led to widespread famine and death.

The summer of 1845 was wet, and the potatoes were stricken with a strange disease. All over the Continent and the British Isles potatoes became black in colour, and started to decay. Alarm at the consequent food-shortage was general, but in Ireland, where potatoes form the main article of food for the population, panic spread.

The cause of this potato disease was then unknown, and efforts to check its progress were unsuccessful. It revisited the countries year by year, leaving famine and death to mark its stay. In the years between 1845 and 1860 a million people died in Ireland and a million and a half persons emigrated to other lands as a direct consequence of the famine. Nothing in those years seemed to stop the blight of the potatoes. Though the later outbreaks were milder than the first widespread devastation, yet even in 1879 at least £6,000,000 was lost in Ireland alone as a consequence of blight.

By 1885 a discovery had been made which pointed to a possible means of control of blight. In that year some Frenchmen successfully treated vines diseased by a fungus with a solution which they called 'Bordeaux mixture.' By 1890 it was clear that by spraying potatoes with this mixture the spread of blight could be arrested, and even to-day outbreaks of potato-blight are treated in this way. Bordeaux mixture consists of 10 lb. of granulated copper sulphate and 12½ lb. of hydrated lime in

[1] See Chapter XXII.

100 gallons of water, and it is applied to the potato crop by means of a sprayer as soon as blight spots are seen on the foliage. About 120 gallons of mixture are applied to each acre.

We are, however, more concerned with the biological means of checking the outbreaks of potato-blight, by the selection of potato varieties which are resistant to the blight fungus. This method of approach had already been tried by workers in the nineteenth century, but their efforts had met with only tolerable success. Expeditions to South America, the home of the wild potato, sent back varieties of wild potato, some of which proved to be fairly resistant to blight, but poor in yield and food value. There were many species which were blight-resistant to some degree, among them the Mexican species, *Solanum demissum*. This last potato could be grown in such conditions that it was almost totally immune from blight, but it bore only a small crop of tubers.

Many nations took a hand in the search for blight-resistant species, and in the twentieth century new and improved methods of breeding were employed. The United States, Germany, Russia, and Britain established research laboratories for the study of potato-blight, and by 1939 visitors to the Chelsea Show were able to see a number of breeds of potato which were known to be resistant to the blight fungus.

Some of these demonstrations were most striking. In the centre of the exhibit stood a flower-pot containing two potato plants. That on the left was a normal commercial breed, already heavily infected by the blight fungus, while the right-hand plant, an immune breed, remained perfectly healthy, although its foliage was actually in contact with the infected plant and was covered by blight spores. This immune plant, a descendant of the Mexican *Solanum demissum* which had been crossed with a good-yielding breed, inherited blight resistance, yet produced a good yield of tubers.

It seemed, then, to the casual onlooker that the struggle to overcome potato-blight was over, yet the experts were faced by increasing problems. In the first place, the blight-resistant potatoes which could be produced in the laboratory by means of the breeding of new types from blight-resistant parents could not compete in yield with many less immune breeds. Many farmers preferred to plant such types as Great Scot, King Edward, or British Queen, magnificent potatoes for food but susceptible

to blight, frost injury, and virus diseases. Perhaps, they reasoned, our potatoes will not be stricken by blight, and if they are, well, we can always check it by spraying with Bordeaux mixture.

Secondly, our knowledge of plant diseases is still incomplete. We may select potatoes which are immune to infection by blight, yet by so doing we may produce breeds which are readily attacked by virus diseases or other infections to which the blight-susceptible potato is normally immune. For instance, every King Edward potato in the world is infected by a virus, which does not affect the health of the plant. Nevertheless, if we graft a King Edward potato on to certain other breeds, such as Arran Chief, the virus induces a severe disease in the hybrid plant so formed. This is but one of many cases where an artificially controlled breeding experiment has led to unexpected and undesired results.

And so the fight goes on. Scientists all over the world continue to investigate the diseases of plants, some hoping that one day they will be able to produce crop plants which are immune from disease, while others confine themselves to hoping that soon our knowledge will allow us to check any serious outbreaks of disease, and so to avoid the devastations of earlier years.

5. Malaria

Malaria is a widespread disease affecting man, and occurs in most districts except the polar regions or waterless deserts. It is particularly prevalent in warm, marshy regions.

Immense damage is caused by the malarial parasite. In India alone over one million persons die from malaria each year. More than six million cases of malaria occur annually in the United States, though because of the skilful treatment few deaths occur. The League of Nations Malarial Commission in 1924 estimated that at least one-third of the population of ancient Greece suffered from malaria, while historians have attributed the decline of the Greek states to this cause. Even in recent times malaria has been an important factor in retarding the development of certain regions.

In 1880 the malarial parasite was discovered for the first time in the blood of malarial patients by the French physician Laveran. Various scientists suggested that mosquitoes were related to the disease in some way, prominent among them being Manson,

who clearly suggested that mosquitoes carried the parasite. It was largely due to this suggestion that Ross in India searched for the parasite in several species of mosquito. At length, in 1897, he was able to announce that he had discovered the parasite on the stomach of the mosquito *Anopheles stephensi.* This discovery was

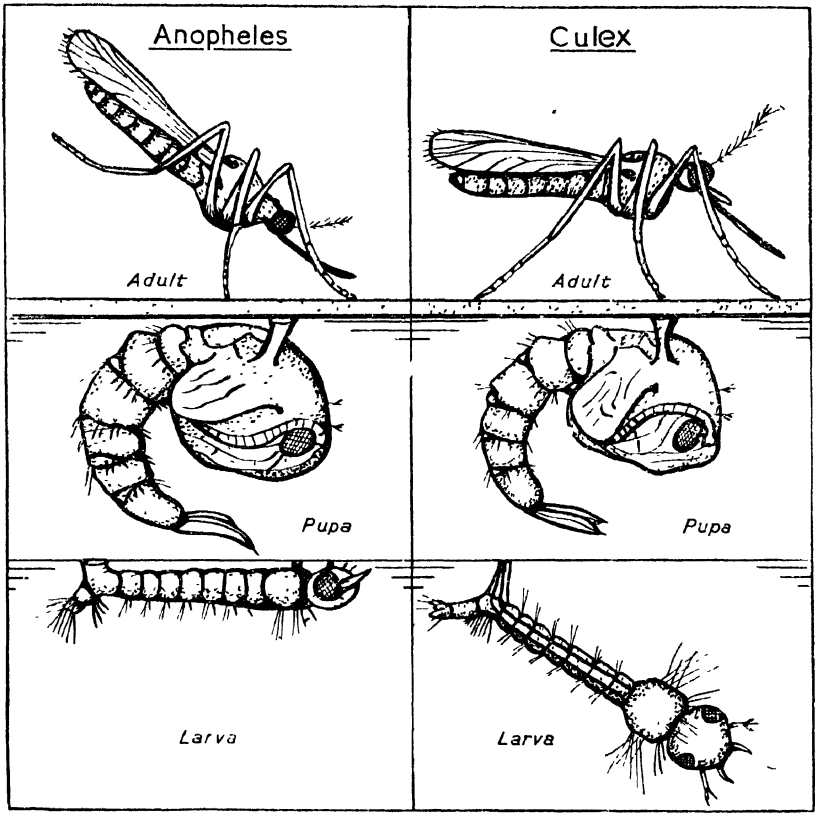

FIG. 125. LIFE-HISTORY OF THE GNAT, CULEX, COMPARED WITH THAT OF ANOPHELES, THE MOSQUITO WHICH CARRIES THE MALARIAL PARASITE

confirmed and extended by later workers, and it was thus clearly established that destruction of anopheline mosquitoes would help to eliminate the disease from severely infected regions.

Preventive measures are directed primarily against the larval and pupal stages of the mosquito. Three main methods are employed—(1) the destruction of breeding-centres, (2) treatment of breeding-centres by oils and poisonous dusts, (3) the employment of the natural enemies of mosquitoes.

Wherever possible, stagnant pools, water-butts, and other breeding-centres of mosquitoes in malarial areas are drained, or, if this is impracticable, a fine film of petroleum oil or poisonous dust is sprayed on the water, destroying the larvæ and pupæ. Aeroplanes are used for the spraying of large areas. It is probable that the new insect-killer known as D.D.T. may prove to be a valuable agent in the fight against the anopheline mosquito.

Spraying methods are expensive, and it is often simpler and

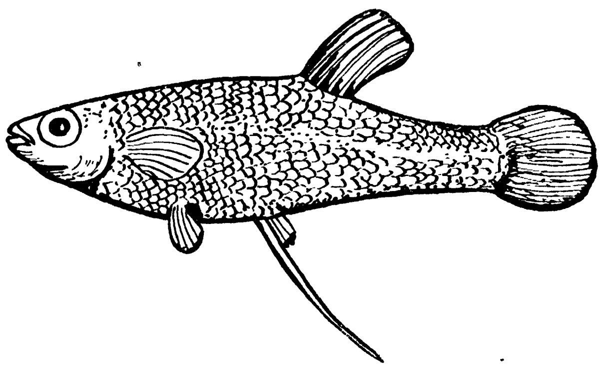

FIG. 126. GAMBUSIA AFFINIS, THE TOP-MINNOW

preferable to stock the waters in which mosquitoes breed with their natural enemies. A great number of animals prey on mosquito larvæ and pupæ, and some of these are suitable for use in artificial mosquito control.

Two fish, the fresh-water top-minnow (*Gambusia affinis*) and the salt-water killifish (*Fundulus heteroclitus*), are extensively used in mosquito control. Gambusia lives in temperate zones, where freezing does not occur, and feeds voraciously on mosquito larvæ. A single fish may consume one hundred larvæ in eight hours, and may even choke in his anxiety to consume all the larvæ in sight. Control by this means is not wholly satisfactory, as often the extinction of the mosquitoes is followed by the death of the fish, which by then have little or no food.

Some plants have proved suitable for mosquito control. Insectivorous plants of the genus Utricularia capture mosquito larvæ, among other insects. Another species of water plant, *Chara fragilis*, appears to discourage mosquito larvæ, and in lakes where this weed grows densely mosquito larvæ are not found.

Therefore, by using the appropriate measures against anophe-

line mosquitoes, scientists can check the spread of malaria and so reduce the amount of disease in many parts of the world.[1]

SUMMARY

(1) Animals and plants influence each others' lives; no animal or plant lives a completely independent life.

(2) Any change in an animal or plant will upset all those other organisms which are influenced by it.

(3) Men control a pest by employing the natural enemies of the pest to check it, or by improving crop plants or animals so that they can resist it.

(4) The prickly pear was controlled in Australia by the use of a small moth. The cabbage white butterfly is controlled by the use of a parasitic ichneumon fly. Malaria is checked by the destruction of the mosquitoes which carry the disease.

(5) Potato-blight is checked by the spraying of potatoes with chemicals to kill the fungus, or by the breeding of potatoes which will resist the disease.

SUGGESTION FOR HOME STUDY

Discuss the meaning of the term 'biological control.' Illustrate your answer with examples.

[1] A previous general description of malaria was given at p. 229.

CHAPTER XXV

LIFE IN THE PAST

Come, dear children, let us away;
Down and away below.

MATTHEW ARNOLD, *The Forsaken Merman*

ANIMALS and plants which lived on the earth many millions of years ago have in some cases left remains of their bodies buried in rocks, thus enabling us to picture life in past ages. The evidence of these remains suggests that the forms of life in the past differed greatly from the animals and plants which inhabit the world to-day.

1. THE PRESERVATION OF DEAD ORGANISMS

Modes of Preservation. Sometimes records of life in the past are through accident preserved almost perfect. In the year A.D. 79 the volcano Vesuvius erupted, and overwhelmed Pompeii, a near-by town, with volcanic mud and ashes. The panic-stricken inhabitants, who had for years regarded Vesuvius as extinct, fled, leaving behind their belongings and those of their number who failed to escape. To-day much of the ashes and mud has been cleared, and a vivid picture may be obtained of life in a Roman town nearly nineteen centuries ago. Buildings, paintings, cloth, wood, and even the meals laid on that fateful day of the eruption have been preserved by the covering of ashes in many places. Unfortunately for the study of past ages, such catastrophes as this rarely occurred.

Amber. Nevertheless, there are still remains in almost perfect condition left for us to discover. In the Baltic region of Europe there is found a substance called **amber.** This substance is nothing more than hardened resin, the gummy substance in pine-trees. Occasionally drops of resin falling from the trees must have trapped forest insects, since we often find these perfectly preserved in blocks of amber (Plate 31). Often it is even possible to dissect the insects found in amber, and to examine their internal parasites. Yet it has been calculated from various data that the amber must represent the resin of trees which flourished nearly forty million years ago.

Fossils. Less spectacular, perhaps, but not less interesting, are the

remains of animals and plants which we find in rocks, and which we call **fossils** (L., *fossilis*, dug up). These remains are less perfect than is the case with those organisms found in amber because in most instances fossils represent animals or plants which have undergone great chemical changes since their death. Usually only the hard parts of organisms remain (*i.e.*, shells, teeth, bones, etc.), and in most cases the original material has become dissolved in the water which percolates through the ground and replaced by minerals such as iron sulphide (iron pyrites) or silicon or calcium compounds, which are deposited in the cavities left by the dissolution of the original materials.

In order for an animal or plant to become fossilized it is necessary that it should be buried soon enough after death to precede the approach of decay. The organism should preferably have died in or near water, as the remains of animals on dry land soon become dispersed by wind-erosion of the land surface. Moreover, the rapidly hardening and mineral-bearing nature of marine or fresh-water deposits contributes to their perfect fossilization. Some of the best records of past life are those of life on the sea-floor, where rapid burial is helped by the constant shifting of sand or mud.

One might naturally expect deeper deposits to represent earlier ages and those near the surface to have been laid down in fairly recent times. It is found that the layers of rocks differ in their structure, and that their nature is largely dependent on the conditions which existed at the time they were laid down. Coal represents the fossilized bodies of trees and other plants, while chalk is filled with the remains of marine organisms, and is in fact largely composed of the shells of countless small animals. We therefore know that at one period great forests covered England, whereas at a later date much of the country was covered by the sea.

2. Rocks and Ages

Layers of rocks are known as **strata** (L., *stratum*, layer). Geologists have calculated from the depth of the various strata and the minerals which they contain the duration of the various ages on the earth. Our present estimates are based on the length of time needed for the decomposition of certain radio-active elements called uranium and thorium. These are present in recently formed rocks, but in older rocks they break down in

time to form lead. We can calculate with reasonable accuracy that half a given mass of uranium will be transformed to lead in about four thousand million years, and so by calculating the proportion of these elements in a specimen of rock we can estimate its age.

It is a peculiar and very interesting fact that we find fewer fossils in the earlier strata; also that many of these differ from

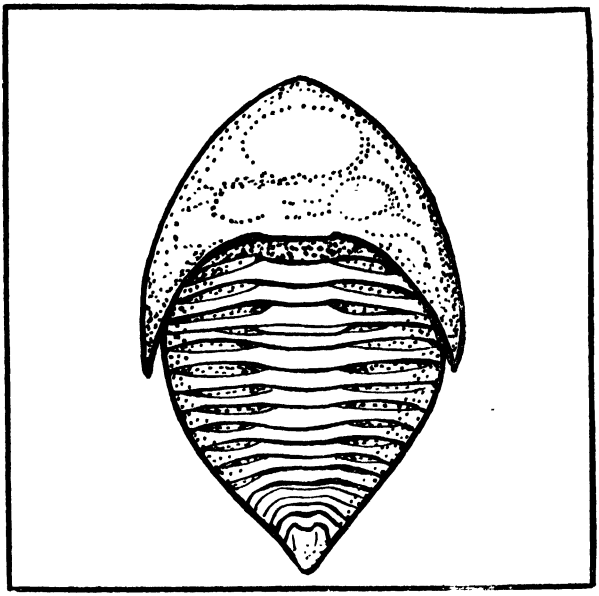

FIG. 127. FOSSIL TRILOBITE
This figure is drawn from a specimen in the author's possession.

any organism living on the earth to-day. For example, the rocks in Wales represent a very early stratum, which by a tilting of the land surface has come close to the surface. In the rocks of Wales we find many remains of the animals which we call **trilobites.** Yet these are absent from most of the later deposits. It appears, therefore, that the life on the world many million years ago differed greatly from the forms of life which inhabit it to-day.

Geology (the study of the rocks) has established the presence of many hundreds of strata, containing many thousands of different fossils, and from this evidence it is now possible to form a reasonably accurate estimate of the climate, topography, and forms of life of the world in the past. The geologist has, for convenience, divided past time into **eras,** each of which is marked

by some significant geological change. These eras have been subdivided into **periods** on the basis of less significant geological changes.

If the earth's surface had not been disturbed in the past by

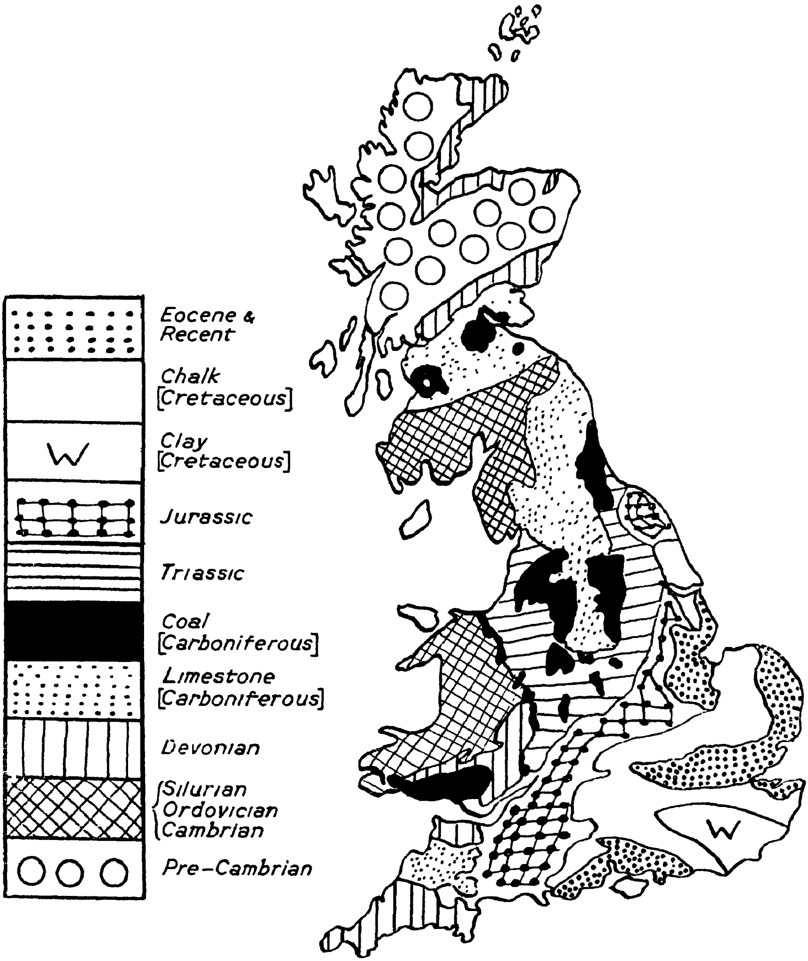

FIG. 128. GEOLOGICAL MAP OF BRITAIN
In this map the approximate areas of the main deposits are shown.

subterranean convulsions one might expect that the surface rocks at any point would represent the later periods of geological time, and that the rocks of the earlier periods would lie far below. In fact, however, so much tilting, erosion, and general disturbance of the strata has taken place that in some regions the earliest

rocks are found close below the soil. We have already referred to the great age of the deposits found in Wales, and a glance at the map below will show that this is by no means an isolated phenomenon. Though simplified, this geological map shows the predominant stratum to be found close to the surface at any point in the British Isles.

A glance at the table of geological time on p. 279 will teach you the approximate age of the rock on which your home may stand, and the most likely fossils to be found in that rock. However, gardens are not good places in which to search for fossils. Gravel-pits, clay-pits, or stone quarries are much better fields for investigation. The bare rock surfaces simplify a search for fossils, and it is pleasant on a sunny spring morning to sit in a sheltered spot in a quarry chipping fossils out of the rock by the aid of a hammer and chisel.

3. The Age of Early Life

Biologists can form a fairly complete picture of living things by means of the careful examination of fossils. Let us suppose that we were bound neither by space nor time, and that we could travel back to the **Cambrian** period, the earliest period which has left extensive fossils. What should we find?

A dreary scene would meet our gaze. Perhaps the most frightening impression would be the cold silence, broken only by the splashing of the waves against a rocky shore. There is no evidence that any land plants or terrestrial animals were present on the earth in those times, so leaving behind the bare, trackless expanses of rock, let us plunge into the sea, where, to judge from the fossils that have been found in Cambrian rocks, we shall find some other forms of life.

Here, indeed, we should find living things, though they would be very different in appearance from those forms of life that flourish in the sea to-day. The most abundant animals to be seen would be the trilobites, which were not unlike huge wood-lice. Sponges, starfish, corals, and other invertebrates are also known to have lived in the seas of this period. It was not, however, until the next great geological period, the **Ordovician,** that any fishes made their appearance.

A few curious 'armoured' fish left their remains in Ordovician rocks, but it was not until the succeeding period that fishes like

those of to-day appeared on the scene. Probably in the Ordovician period the land also bore traces of life in the form of primitive ferns.

Continuing our journey through time, we pass through the **Silurian** and the **Devonian** periods. Early fishes, covered by bony plates were present, together with sharks, and in the Devonian these became the dominant forms of life. Coral reefs

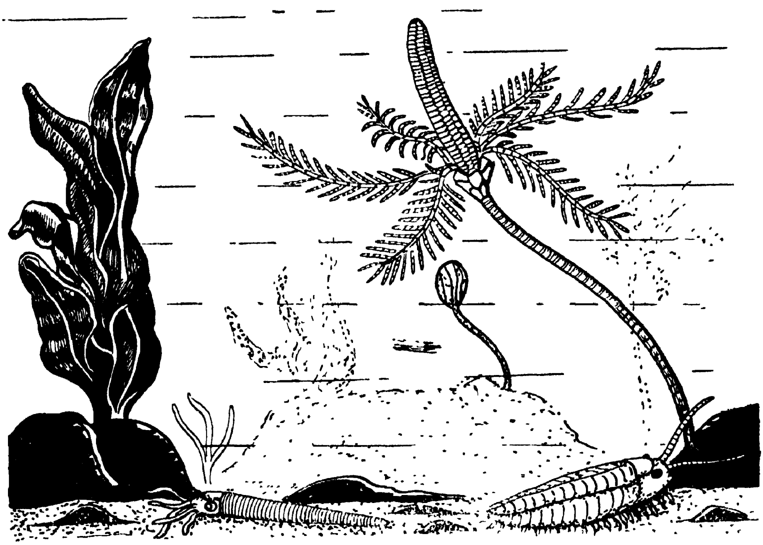

FIG. 129. RESTORATION OF A MIDDLE-SILURIAN SEA BOTTOM
In the left foreground is a straight-shelled Nautiloid, and in the right foreground a Trilobite is shown. Behind the Trilobite are two specimens of Crinoids, or Sea-lilies, one open and one in the closed position.

were abundant, but the trilobites which we discovered in the Cambrian period have by now begun to decline. There is considerable evidence that the Devonian period was characterized by a drier climate than the earlier periods, and that a drying up of lakes and streams may have speeded up the evolution of land animals. The remains of spiders have been discovered in rocks of the Devonian period, and in the past few years the remains of early amphibians have been found in the late Devonian rocks of Greenland. One trace of a land animal of that period is provided by a large, single three-toed footprint discovered in the rocks of Pennsylvania in the United States of America. We can, however, only guess at the appearance of that huge monster, who, lumbering through the lonely swamps, left a deep footprint which has by some chance been preserved for perhaps three hundred million years.

After the dry, hot climate of the Devonian, it is surprising to find that moist tropical swamps flourished in the next period, the **Carboniferous.** The moist climate favoured the growth of vegetation, and the residue of the vast forests of this period remains to us in the form of coal. The 'trees' of these forests

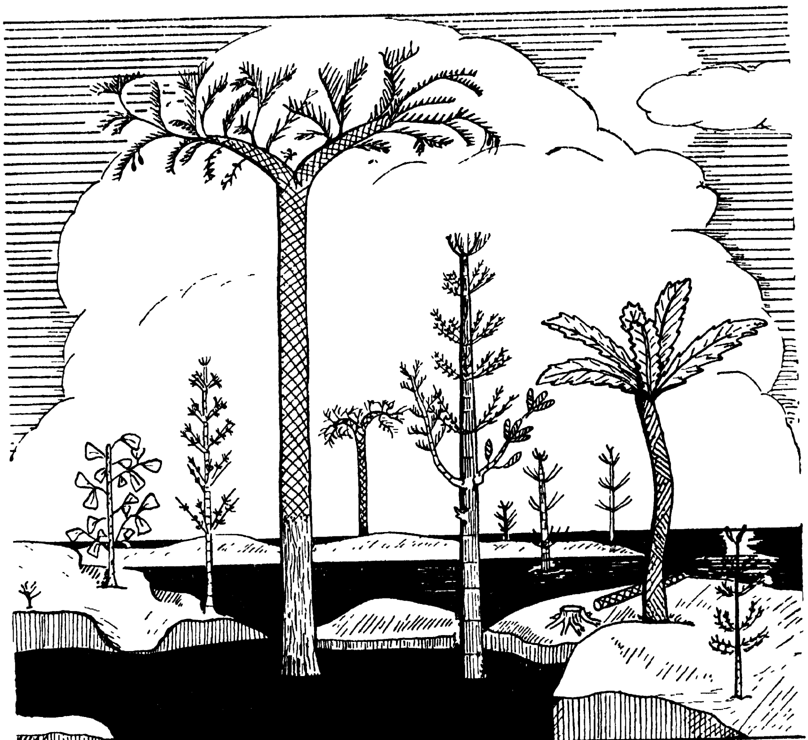

FIG. 130. SOME PLANTS OF THE CARBONIFEROUS PERIOD
Details of plants redrawn after Seward.

were giant ferns, some primitive forms of the related 'club-mosses,' and 'horsetails,' and primitive forms of pine-trees.

Insects were abundant in this age, and attained sizes that they have never reached since. Cockroaches four inches long were common, and some of the dragon-flies had a wing-span of nearly three feet! Land animals were mostly amphibious, and were in appearance not unlike the present-day salamanders, though they exceeded these in size.

The following period, the **Permian,** was dry, and widespread

ice and glaciers made conditions severe for living things. Towards the end of this period terrible upheavals of much of the earth's surface, resulting in the formation of the Appalachian mountains, are believed to have occurred.

This great upheaval at the end of the Permian marks the end of the **Palæozoic** (Gk., *palaios*, ancient; *zoe*, life) era of life.

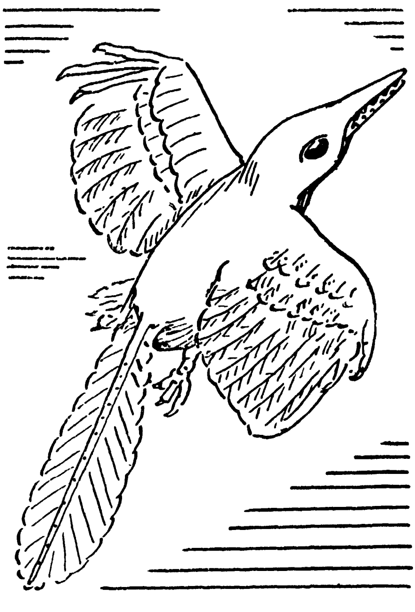

FIG. 131. ARCHÆOPTERYX, THE EXTINCT 'BIRD-REPTILE'

This reconstruction of Archæopteryx is based on the fossil remains which have been found in deposits of the Jurassic period

4. THE AGE OF REPTILES

The next great era, the **Mesozoic** (Gk., *mesos*, middle), consisted of three periods, the **Triassic,** the **Jurassic,** and the **Cretaceous.** Altogether, it lasted for nearly 110 million years, and during this time the dominant animals were the scaly reptiles. Today the reptiles are represented by snakes, crocodiles, tortoises, and lizards, but in the Mesozoic they often assumed vast and monstrous shapes. The Mesozoic has been termed the "age of reptiles." Small, hairy mammals also appeared during the Mesozoic, but these were dominated by the numerous reptiles. In the middle of the Mesozoic era birds must have evolved from reptiles, since we find fossil remains of creatures which were half-bird and half-reptile (Fig. 131).

Reptiles reached their highest point of development in the Jurassic period. They dominated the land, the sea, and the air. Nevertheless, in spite of their large bulk, their brains were often no larger than a hen's egg; there is little doubt that these small brains proved inadequate to control their huge bodies, and that the disproportion between the size of the brain and the rest of the body contributed to their extinction.

Some of these enormous reptiles, which were called **dinosaurs,** were carnivorous, but the most gigantic remains we find appear to have been herbivorous. Cetiosaurus, a herbivore whose

remains are found in Oxfordshire, had an estimated length of nearly seventy feet and a weight of nearly forty tons! Tyrannosaurus, a carnivore of the Cretaceous period, was nearly fifty feet in length, and had jaws four feet long. It was beyond doubt the most formidable animal that has ever lived on the earth.

In the seas the dominant types among the 'animals without backbones' were the **ammonites,** whose remains are abundant in the Jurassic rocks, but which disappear in the Cretaceous

FIG. 132. BRONTOSAURUS, A GIANT DINOSAUR OF THE JURASSIC PERIOD

This is an imaginative reconstruction, based on fossil remains, of a creature that had an estimated length of about 65 feet and a weight of about 40 tons; its brain probably weighed about a pound.

deposits. Their nearest living relative is the 'pearly nautilus' which floats on the surface of tropical seas, with a head and tentacles projecting from the opening of the shell.

The end of the Mesozoic era must have been a time of appalling earth upheavals. The Rocky Mountains of North America were formed at this time. Great extinctions of life must also have occurred. Just what conditions caused the extinction of the great reptiles we may never know, but during the vast upheavals at the close of the Mesozoic the giant reptiles vanished from the earth, leaving only their smaller relatives, the lizards, snakes, turtles, and crocodiles, together with the small mammals and birds, to continue the story of animal life.

5. The Age of Mammals

Only sixty million years have elapsed since the end of the Mesozoic era. We are ourselves in the next era, the **Cenozoic** (Gk., *kainos*, recent) or 'age of mammals.' In the early Cenozoic, during the **Tertiary** period, conditions were warm, and mammals spread over the earth. The following period, the **Quaternary,** in which we are still living, was a cooler period, and was characterized by ice-ages, when sheets of ice spread from the poles towards the Equator and caused great migrations of animal life.

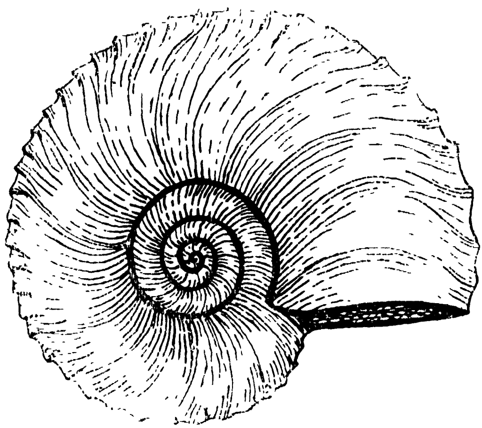

Fig. 133. Fossil Ammonite, Cardioceras cordatum
This figure is redrawn after Woods and is slightly over actual size.

Finally, from among the mammals and before the onset of the Ice Ages, man emerged, and, because of his intelligence, he now holds a dominant position. Yet the evidence suggests that man has been present on the earth for considerably less than two million of the 5000 million years or more that life has been on the earth.

The History of the Horse. In many of the more recent deposits we find fossil bones of horses, which are not very unlike the bones of horses living to-day. But as we investigate earlier deposits we find that those bones which we can identify as being those of horses are very different from the later forms. Enough remains of early horses have been discovered to allow us to picture the ancestors of the modern horse.

If we could have been in America in the **Eocene** period, about sixty million years ago, we might have seen a little animal about the size of a fox darting into the forest at our approach. This animal had four toes on each of its fore-feet and three toes on

each of its hind feet. It has been called **Eohippus** (Gk., *eos*, dawn; *hippos*, horse).

In later rocks we find no remains of Eohippus, but instead we find remains of larger horses with fewer toes and greater skulls. Our evidence suggests that these are the descendants of Eohippus. A search in still later rocks reveals the remains of horses more

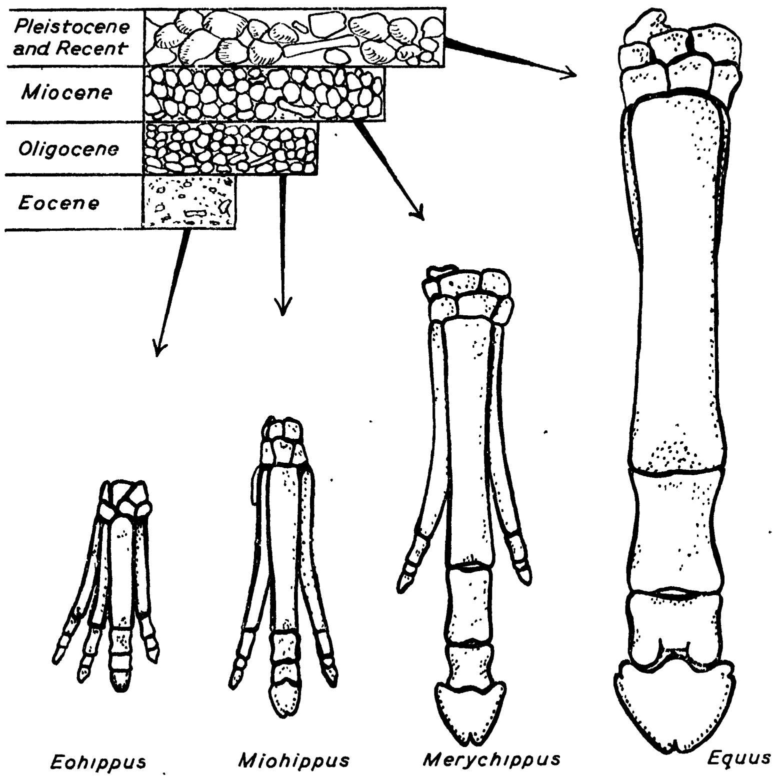

FIG. 134. EVOLUTION OF THE FORE LIMB OF THE HORSE

like those living to-day. Only one toe now remains on the fore-feet, although remnants of the other toes persist as vestiges.

It would seem, therefore, that the horse has evolved considerably in the past sixty million years, probably in response to changing conditions of life and climate.

Some other forms of life, such as ammonites and trilobites, were less successful in their attempts at adaptation. They did not evolve in response to the changing conditions around them, and so they died out, leaving no direct descendants.

A TABLE OF GEOLOGICAL TIME [1]

ERA	PERIOD	DURATION OF PERIOD IN MILLIONS OF YEARS	FLORA	FAUNA
Cenozoic (Age of Mammals)	Pleistocene (Quaternary)	?		
	Tertiary: Pliocene and Miocene	24	Dominance of flowering plants (Angiosperms).	Evolution and dominance of mammals. Emergence of man.
	Tertiary: Oligocene and Eocene	35		
Mesozoic (Age of Reptiles)	Cretaceous	60	Dominance of pines and other Gymnosperms and evolution of flowering plants.	Evolution and dominance of reptiles. Evolution of birds. Ammonites appear, but later become extinct.
	Jurassic	25		
	Triassic	25		
Palæozoic	Permian	40	Ferns and primitive pines.	Evolution and spread of amphibians, insects, reptiles.
	Carboniferous	75		
	Devonian	40	Primitive ferns and primitive pines.	Evolution of fishes and land invertebrates.
	Silurian	25		
	Ordovician	60	Algæ.	Marine invertebrates, trilobites, etc.
	Cambrian	90		

SUMMARY

(1) Some of the organisms which lived in the past have been preserved in rocks as fossils.

(2) The depth and chemical composition of rocks allows us to estimate their age with reasonable accuracy.

(3) In the earlier rocks we find only remains of the simpler forms of life.

(4) The fossil remains found of animals and plants suggest many forms unlike any known to-day.

(5) The evolution of animals and plants which we note in the fossil record corresponds with marked geological and climatic changes, to which it is undoubtedly related.

SUGGESTIONS FOR HOME STUDY

(1) In what parts of England would you expect to find fossils of (*a*) ammonites, (*b*) trilobites, (*c*) early fish, (*d*) ferns?

(2) What conditions are necessary for the preservation of dead organisms?

[1] The data in this table are in accordance with the estimates presented on the geological column exhibited in the Museum of Practical Geology, London.

CHAPTER XXVI

THE COMING OF MAN

Our ancestors are very good kind of folks; but they are the last people I should choose to have a visiting acquaintance with.

R. B. SHERIDAN, *The Rivals*

1. THE REMAINS OF PRIMITIVE MAN

THE study of man's ancestors is based on two main sources of information. The first of these is the study of the structure of early men, as evidenced by those remains of their skeletons which have been preserved as fossils. The second is the preservation of implements, pottery, paintings, and other records of the activities of early man.

An interpretation of the skeletal remains of the earliest men presents certain difficulties, because we find that there are the same number of bones in the skeletons of men and apes. Moreover, the further back our knowledge takes us, the greater are the similarities between the skeletons of early men and those of early apes.

Such differences as do occur lie mainly in the skull, though the erect posture of man, in contrast to the shambling gait of apes, is reflected in the length and straightness of his leg-bones and the modification of his feet for walking.

The skulls of modern men are distinguished from those of the earliest men and from those of apes by three main features:

(1) The size of the brain-case is considerable in relation to that of the face and jaws.

(2) The prominent brow-ridges of apes have become reduced in modern man.

(3) Modern men have more prominent chins than have apes, but their jaws are smaller and less projecting.

All the available evidence suggests that both the human race and the modern apes evolved from some common ancestor more than a million years ago. The evolution of man is well illustrated by the remains of four types[1] of primitive man, which, in the order of their appearance on the earth, are represented by Java man, Pekin man, Neanderthal man, and Cro-magnon man.

[1] The four types chosen as examples are only some of the better-known types of primitive man.

In 1892 Dr Dubois, of the Dutch army medical service, discovered in Eastern Java a fossil skull-cap, some teeth, and a thigh-bone which were undoubtedly the remains of an ape-like early man, who was estimated to have lived about 500,000 years ago. The brain in this specimen was about midway in size

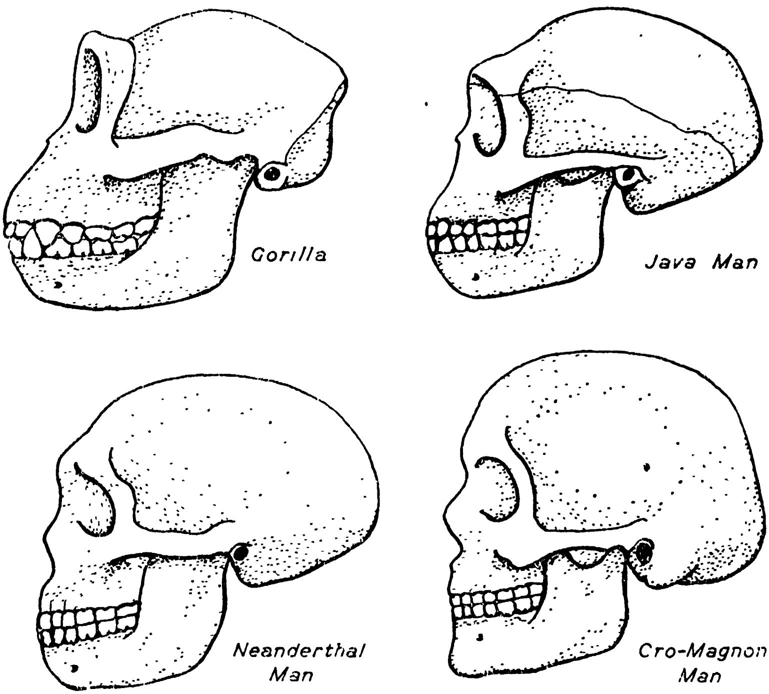

FIG. 135. SKULLS OF EARLY MEN COMPARED WITH THE SKULL OF A GORILLA
The series illustrates the reduction of the brow-ridges and jaws, and the change in the shape of the brain-case. For modern man see Fig. 57.

between that of an anthropoid ape and that of modern civilized man; the brow-ridges were large, but the femur was straight, and definitely human. Casts of the brain (which were taken by pouring plaster into the interior of the skull) suggest that Java man had the power of speech. An interesting feature of this discovery was provided by Dr Dubois' announcing, in the 1880's, his intention of going to Java, where, according to his calculations, he expected to find the remains of primitive man. Rarely have scientific expectations been so completely justified by results.

In the 1920's a Swedish expedition discovered in China the remains of another early man (Plate 31), who, it is estimated, lived

not much later than Java man, and resembled him in so many respects that the two types may possibly represent varieties of the same species. Pekin man, as he is called, lived in caves, made flint implements, and used fire. His brain capacity was little less than that of some primitive races living to-day.

In Europe several discoveries of early skulls suggest that the men who lived 500,000 years ago in the west were more like modern men than was Java or Pekin man. Most of these Western early remains are so fragmentary that the matter is still under dispute.

Some remains of a later species, a well-known type called Neanderthal man, have been discovered in Europe, together with flint implements. This man was about 5 foot 4 inches high, and had a massive chest and big bones. His brain was as large as the average brain of modern civilized men, and even larger in some cases. The frontal region of the brain, however, which is thought to be concerned with the higher powers of reason, was relatively small.

Neanderthal man lived in Europe about 200,000 years ago, but was superseded during the last Ice Age, about 40,000 years ago, by a type called Cro-magnon man, whose remains resemble the skeletons of modern men so closely that Cro-magnon man is included with modern men in the species *Homo sapiens*.

The exact relationship between early men is still a matter of dispute. Clearly many varieties, and possibly even species, of sub-human men must have evolved from a common ancestor during the early stages of man's evolution, and probably many of these early men were ape-like in appearance. Our present evidence does not allow us to decide to what extent intermarriage may have taken place between these early varieties of men. During excavations at Mount Carmel, Professor Dorothy Garrod discovered skulls of Neanderthal man, together with others of a more 'modern' type, while in neighbouring graves skulls were found of a type intermediate between these two forms. Such evidence suggests that intermarriage probably occurred between the Neanderthal and Cro-magnon types.

2. Implements, Vessels, and Paintings

Many remains of the handiwork of early men have been preserved, and these record some of the activities of primitive

man. Chief among these remains are the implements made of flint and other stones.

Primitive man discovered that sharp-edged tools could be made by striking flakes from blocks of flint. Many of these flint implements have been found in cave deposits and river gravels, sometimes associated with the remains of early men.

A Simple Table of Prehistoric Times

Approximate Number of Years Ago	Type of Man	Degree of Culture
13,000–Recent	Modern man	Agriculture. Domestication of animals. Use of metals replacing stone tools. Villages.
40,000–13,000	Cro-magnon man	Flint implements. Cave paintings.
250,000–50,000	Neanderthal man	Flint implements. Cave dwellers.
100,000–500,000	Java man Pekin man	Use of fire. Cave dwellers. Flint implements.

In general, two main periods of flint manufacture are recognized. Those implements of the earlier, or **Palæolithic** (Gk., *palaios*, old; *lithos*, stone) period, although skilfully made, are crude in appearance when compared with the products of the later **Neolithic** (Gk., *neos*, new) period. The intervening **Mesolithic** period shows features intermediate between the other two periods. A general-purpose hand-axe is the typical large tool of the Palæolithic period, together with a variety of flake-tools, while during the Neolithic period a variety of delicately flaked axes, scrapers, borers, knives, and other tools were fashioned for various purposes.

The other great discovery made by man in Palæolithic times was that of the art of fire-making. During the Early Stone Age (530,000–10,000 B.C.) the greater part of Europe was covered, at intervals, by ice sheets. The weather was intensely cold at the peak periods of glaciation, and men lived in caves. Between the 'Ice Ages' the weather was much warmer, almost tropical, but men continued to live in caves for shelter.

Some of the caves inhabited by the primitive men of later Palæolithic times still contain paintings which they made on the

CULTURAL PERIODS OF EARLY MAN[1]

Cultural Period			Time
PALÆOLITHIC			
Lower Palæolithic. Abbevillean (Chellean), Acheulean, Clactonian. Early Levallois.			*c.* 550,000–250,000 years ago
Middle Palæolithic. Late Acheulean and Clactonian. Levallois. Moustierian.			*c.* 250,000–100,000 years ago
Upper Palæolithic. Aurignacian. Solutrean. Magdalenian.			*c.* 100,000–12,000 years ago
MESOLITHIC			*c.* 12,000–5000 years ago
LATER PERIODS			
Western Europe	*Western Asia*	*China*	
Mesolithic	Neolithic	Mesolithic	5000–4000 B.C.
Mesolithic	Chalcolithic[2]	Mesolithic	4000–3000 B.C.
Neolithic	Chalcolithic Bronze	Neolithic	3000–2000 B.C.
Bronze	Bronze, then iron	Bronze	2000–1000 B.C.
Iron	Iron	Iron	1000–500 B.C.

walls more than 100,000 years ago. Some of these paintings, of which two examples are reproduced at page 286, show that primitive man had an acute perception of his surroundings and a considerable artistic skill in the depicting of the animals which he hunted.

In the Mesolithic period (see table) the ice-sheets receded in the Northern Hemisphere, and the climate, animals, and vegetation like those of to-day developed.

While Europe was still in the Middle Stone Age, the peoples of the Near East began to give up a life of hunting and gathering. They formed into larger communities and commenced agriculture, the domestication of animals, the use of copper, the

[1] This chronological table was prepared by T. K. Penniman, M.A., Curator of the Pitt Rivers Museum, Oxford. Palæolithic 'dates' follow C. F. C. Hawkes, *Museums Journal*, September 1941.

[2] During the Chalcolithic periods, both stone and metal were used for tool-making.

making of pottery and textiles, writing, and music. This probably occurred between 6000 and 5000 B.C.

And so with the use of copper metal implements gradually came to replace those of stone. The Bronze[1] Age had spread to Britain by about 1800 B.C., and was in its turn succeeded by the Iron Age. The replacement of stone by metal implements,

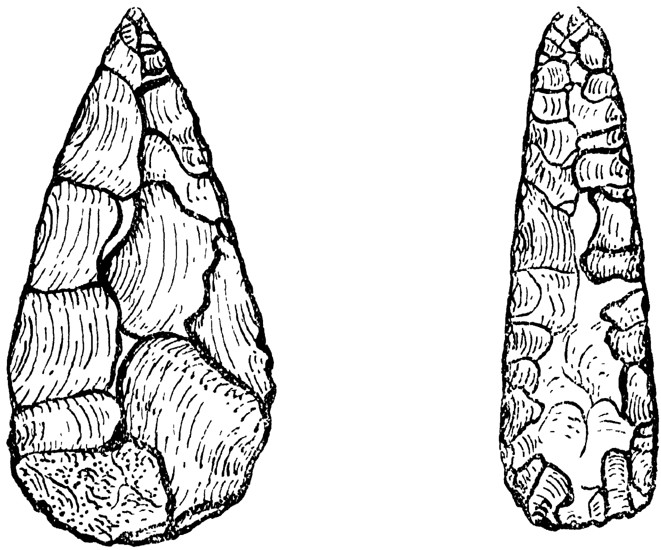

FIG. 136. HAND-AXE OF THE PALÆOLITHIC PERIOD (*left*) CONTRASTED WITH MORE FINELY WORKED AXE OF THE NEOLITHIC PERIOD (*right*)
These figures were drawn from the specimens in the Pitt Rivers Museum, Oxford.

together with the general increase in civilization of which this formed a part, was a gradual process, differing in duration in different parts of the world, and during the New Stone Age in Britain the use of bronze and the development of civilization was already spreading out from the Near East over Asia and Europe. Eventually iron became the dominant material for implements, although even in recent times the Australian aborigines and certain other primitive races of mankind have continued to use stone tools.

3. REASON AND THE HUMANITY OF MAN

Our evidence indicates that mankind and apes evolved from some common ape-like ancestor. Throughout this book the

[1] Bronze consists of an alloy of copper and tin, sometimes with the addition of zinc, lead, or silver. In general it is made up of about 90 per cent. copper, 10 per cent. tin.

structural and functional similarities between man and other living things have been emphasized. Let us therefore close this chapter with a survey of the features which distinguish man from the ape and other animals.

FIG. 137. ROCK PAINTING FROM TORMON

This painting was in red and is here redrawn after Obermaier, approximately one-third the size of the original.

Man is chiefly remarkable among animals for his powers of conceptual thought and reasoning, which have evolved together with the ability to speak. Whereas other higher animals will, when hungry, make a noise indicating hunger, and will search for any food, man may consider particular foods and then ask for a plate of steak and onions. In doing this, man is considering the situation on the basis of his past experience. When man is confronted with an unusual problem he will seek for a possible solution in terms of past experience. This power of associating past events to meet a new situation involves a **power of reason**, which is that which

FIG. 138. WALL PAINTING OF A GALLOPING HORSE FROM ALTAMIRA

This painting was in red and is here redrawn after Breuil and Schmidt, approximately one-fifteenth of the original size.

man possesses in contrast to other animals; they are forced to solve any new situation to which they are unaccustomed, as it arises, without the aid of conclusions derived from past experience.

We often attribute our emotions to animals, but the evidence proceeding from experiments on animal behaviour has not shown that either man's emotions or his power of reasoning are shared by lower animals. The spider's web would at first sight seem to

be a clever construction, but experiments show that the process of building is governed by instinct, not reason.

The more advanced animals show a greater capacity for learning than do the simpler forms. If a tunnel be constructed with two branches, the one leading to food and the other to an electric shock, the number of trials and errors undergone by an animal allow us to assess its learning ability. While earthworms need several hundred trials before they can choose the right path, crayfish need only about fifty trials, and the higher mammals need only one or two.

The so-called 'intelligence' of some of the higher mammals is an extension of this trial and error method. For instance, we may put food in a box to which access is achieved by the unfastening of bolts or catches. Many mammals will learn to open such a box, but their first few attempts are based purely on trial and error, and any success achieved is only a happy accident. When man is presented with a like problem he will think out a possible method of approach and then proceed to test his idea. An element of reason therefore characterizes his behaviour.

We see the beginnings of such a power of reason in the highest apes. A scientist called Köhler tried to find out what untaught chimpanzees could achieve by putting food out of their reach, but providing boxes and sticks which they could use. They piled boxes one on another to reach food, and even fitted two sticks together to reach for an especially distant piece of food. In these actions some degree of insight or understanding of the unusual situation was perceptible.

Yet these were unusually intelligent animals. Most of animal behaviour, even in the case of monkeys and apes, seems to be governed by instinct. Female baboons whose young have died will carry the corpses until they putrefy and mummify. Yet this is not an expression of great grief, but a response to a contact stimulus. The female baboon will react in the same way to any small, furry object placed in her arms.

Reason is only one of the ways in which man differs from other animals. Among other unique features of man we find (*a*) his extreme adaptability (*e.g.*, European town-dweller and Australian aboriginal hunter), which permits a wider distribution than that of most animals, (*b*) his traditions and religious beliefs, (*c*) his use of his hands and manipulation of implements, (*d*) his relatively slow development and great post-maturity period. All

CHAPTER XXVII
THE THEORY OF EVOLUTION

Some call it evolution,
And others call it God.
W. H. CARRUTH, *Each in His Own Tongue*

THE belief that living things are related to one another and that they must therefore have been derived from one or more common ancestors is now so generally accepted that it is well to realize that this concept of **organic evolution**, as it is called, is a fairly recent development of biological thought.

The theory of an evolution of living things was not carefully investigated until the eighteenth century, although the idea had been foreshadowed by ancient Greek thought nearly two thousand years before. During the intervening period most of the authority on scientific matters was in the hands of the clergy, and many of these believed that the variety of living things on the earth were separately and simultaneously created, as is suggested by the Book of Genesis. Many eminent Church authorities, among whom were St Gregory of Nyssa, St Augustine, and St Thomas Aquinas, admitted the possibility of organic evolution, but their conclusions received less attention than they merited from clergy and laymen alike, who found difficulty in fitting these views to the Biblical story.

When the revival of scientific learning took place, at the time of the Renaissance, the idea that living things have evolved from some early form of life recurred to scientific workers.

1. THE AGE OF THE EARTH

Most of the early ideas on evolution, however, conflicted with contemporary estimates of the age of the earth, which were based on evidence from the Bible. A theory of organic evolution would require that the earth's age should be hundreds of millions of years, yet the seventeenth-century Archbishop Ussher had estimated by careful calculations that the earth was less than six thousand years old and, moreover, that God had specially created man on October 4, 4004 B.C., at 9 A.M.

Even fifty years ago geologists and physicists would not admit that the earth could be more than twenty millions of years old, but to-day reliable evidence is available which allows that the age of the earth may exceed five thousand million years. One line in our present evidence is based on the time required for the decomposition of certain radio-active elements found in rocks. The minerals uranium and thorium are present in fairly recently formed volcanic deposits, but are less abundant in older rocks. It is known that these elements break down gradually into a series of radio-active substances which finally form lead, and it may be calculated with reasonable accuracy that half of any given mass of uranium will be transformed to lead in about four thousand million years, assuming that the rate of decay has always been the same as at present, as seems most likely. Therefore, by calculating the amount of lead present in any rock, geologists can now assess with fair assurance its age. They estimate that life originated probably more than a thousand million years ago. It is not surprising that the early scientists, who did not possess the means of assessing evidence we now have, should have been cautious about the theory of evolution, since in the few thousand years of which we have any historical record, one could not expect any very striking changes in living organisms to occur.

However, the evidence to-day for organic evolution is overwhelming, and most scientists have no hesitation in saying that the many and varied living things on the earth are related to one another, and that they have evolved from one or a few common ancestors. Thus, human beings and apes are believed to have evolved from some ape-like ancestor. Carrying the process still further back, it is most probable that men, apes, dogs, cows, and all other mammals had a common reptilian ancestor, which was probably not unlike some of the lizards we find on the earth to-day.

It is uncertain what the ultimate ancestor of the living things may have been, though the exceedingly simple structure of the bacteria and the viruses suggests that they bear close relationship to the first form of life. Some authorities believe that the earliest form of life was in appearance something like an amœba, but which must, however, have been capable of photosynthesis, or in some other way independent of other living things for its food.

We may summarize the evidence for evolution under a few main headings.

2. The Evidence for Evolution

Comparative Anatomy. During the seventeenth and eighteenth centuries scientists accumulated a great deal of data as the result of their studies in the anatomy of animals and plants. When comparisons were made between the anatomy of various

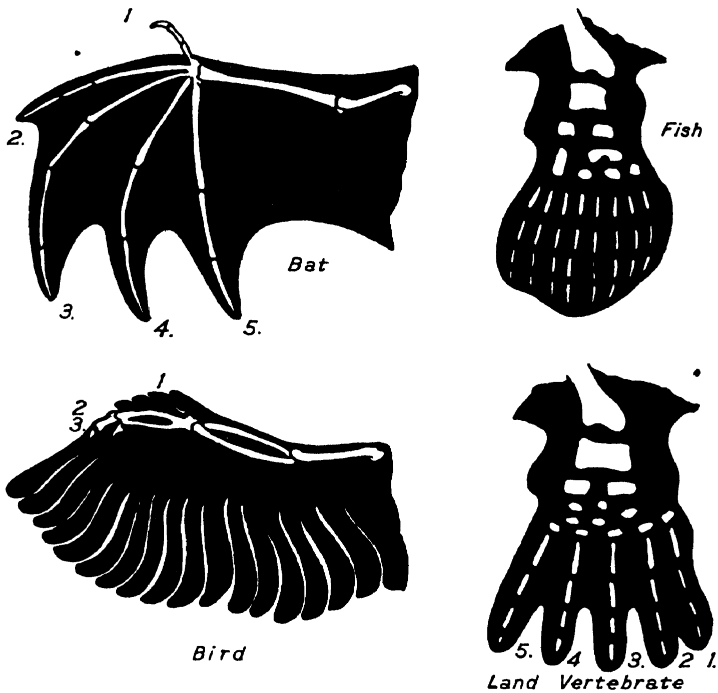

Fig. 139. Fore-limbs of Vertebrates

Above are shown the bones of the hand in a bat, a bird, and an extinct fish (Osteolepis), compared with the bones of a typical land vertebrate. See also Fig. 58.

animals or plants the striking discovery was made that many organs which at first sight seemed dissimilar were in fact built on the same fundamental plan. This principle of **unity of type** is well illustrated by reference to the fins of fishes, the wings of bats and birds, and the hands of land vertebrates (Fig. 139). If we examine the bones of these limbs we find that there is a great similarity of pattern, although in the different organisms they serve different functions.

The study of comparative anatomy has also shown the presence of **vestigial organs** in some animals. These are organs which

have no apparent function, and their presence would be inexplicable if it were not for the consideration that animals possessing such organs have evolved from others in which these organs were functional. As an example of this functional evolution, let us take the rudimentary limb-girdles which are found in snakes. These can be of no use to these animals, which are without legs, yet if we assume that snakes are the descendants of an ancestral form possessing legs—which the modern forms have lost because of their method of locomotion—the presence of a limb-girdle at once becomes clear. Men have a few tail-bones and a number of muscles attached to their ears, yet none of us have long tails while few of us can waggle our ears. Yet these vestigial organs indicate that man's ancestor had a tail and could move his ears.

Classification. The idea of a unity of type shows us that often, in spite of differences of structure, living things can be related to one another. When all the forms of life that we know on earth are arranged in the order of their relationships to one another we find that they fall naturally into a very gradually ascending order of complexity. Thus, for example, we can trace a very complete series of ascensions between fish and men. All the intermediate stages between fins and hands may be found in amphibians and reptiles.

It is true that there are certain gaps between the simplest and the most complex forms of life, yet we can by comparative anatomy and classification trace a fairly complete series, from Amœba to man and from the simplest water-weed to the most complex flowering plant. This complete series is best explained by the theory that the more complex types have evolved from the simpler types.

If we accept this explanation we must then interpret the simple forms, like Amœba, which still live to-day, as the direct and almost unchanged descendants of one of the earliest living things to appear on the earth.

The Study of Development. Sometimes two adult animals appear very dissimilar, yet if we examine their development we find that they are, in fact, closely related. At first sight the barnacles would not seem to be related to the prawns and other crustaceans, yet the larvæ of these forms are very similar and indicate a close relationship between the adult forms. Marine worms and limpets are unlike in appearance, but have similar

larvæ. The animals with backbones show remarkable resemblances in their early stages. The embryos of a fish, a bird, and a man are surprisingly similar.

When the gill-clefts of a very young human being were first noted it was suggested that during their development animals passed through stages in which they resembled their ancestors. It would be more strictly true to say that many of the developmental stages of animals resemble the early developmental stages of their ancestors.

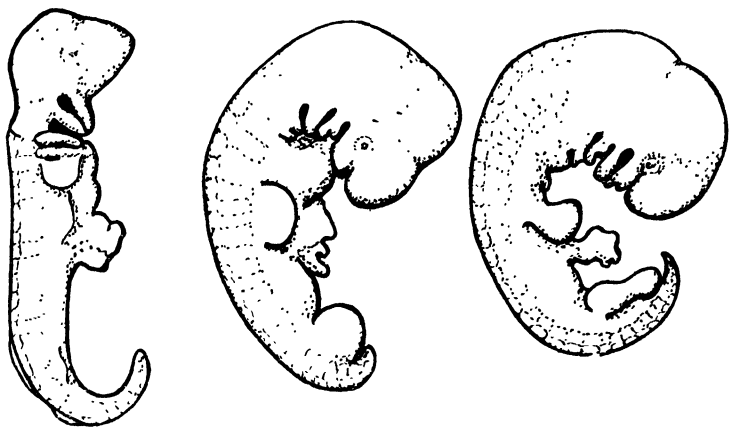

FIG. 140. CORRESPONDING EMBRYONIC STAGES OF A SHARK, A CHICK, AND A MAN

The embryos have been drawn to the same size for ease in comparison.

We can best account for the close resemblances between the developmental stages of animals by suggesting that their adult stages are closely related.

The Record of the Rocks. When men began to investigate the rocks they found preserved in them as fossils the remains of animals and plants. The structure of some of these remains did not resemble that of any of the known forms of life. Many of the early scientists, influenced by the Church's teachings, believed that these fossil remains were left by Noah's flood, or else placed there by the devil to test the faith of the true believers. Indeed, the bones of a giant salamander, unearthed in 1726 in Switzerland, were labelled "Man; witness to the Deluge" and described by the motto

> O, sad remains of bone, frame of poor man of sin,
> Soften the heart and mind of recent sinful kin!

Geologists to-day place a more accurate interpretation on the fossil remains of animals and plants; they have found fewer fossils in the deeper and earlier rocks and, moreover, have discovered that the fossils in early rocks are remains of simple animals and plants only. More advanced forms are only found in more recent rocks. In fact, the later the rock the more complex types does it contain, until we find that the most recent rocks contain fossils of nearly every known living thing to be found on the earth to-day. An evolution of living things would seem to be the only possible explanation of this kind of succession of fossil types in rocks.

The Distribution of Animals. If any further evidence for evolution were needed it is to be found when the geographical distribution of animals and plants is studied. It is found that animals living in the same locality often resemble one another and differ from types in other localities. For example, in the case of the wild mammals of Australia the females all have a pouch in which the young are carried, a feature shared by few other animals in other parts of the world, although fossils of these **marsupials,** as they are called, are found in many places. This fact may be explained by the suggestion that Australia has been sufficiently separated from the rest of the world to allow the direction of evolution to proceed there more or less independently of that which took place elsewhere in the world. Apparently the more advanced mammals found elsewhere did not evolve in Australia, and their position as dominant animals is occupied by marsupials.

Some islands which are well separated from the mainland, are populated by animals which are peculiar there and are not found elsewhere. Islands which are nearer to the mainland, however, contain for the most part species which also live on the adjacent mainland. Probably an evolution of type has proceeded independently on islands well separated from any mainland, while islands near the mainland are so often colonized by mainland forms that new types are less likely to evolve.

3. The Theories of Evolution

By the end of the eighteenth century there had been assembled a great deal of evidence for an evolution of living things, which had arisen from the researches of anatomists, geologists, and

naturalists, but most scientists found it difficult to relinquish the old tradition that species had been separately and simultaneously created and were unalterable. Thus Baron Cuvier, a very learned and able geologist, accurately described many fossil remains, but could only account for their distribution by suggesting that a number of past catastrophes had annihilated all forms of life, and that each catastrophe had been followed by a new creation of living things. Other workers believed that fossil remains bore witness to the Great Flood, but these theories were short-lived, for in 1809 the first of the two great theories of evolution was published.

Lamarck's Theory. Jean Baptiste Lamarck (1744–1829) (Plate 30) was born at Bazentin, in Picardy, and was educated at a Jesuit college. In 1761, during the Seven Years War, he entered the army, but was forced by poor health to leave it. Later he studied medicine and botany. In 1788 Lamarck took a post at the Jardin des Plantes, in Paris. In 1793, at the age of fifty, he turned to a study of zoology, and in 1802 he invented the word biology to include the study of animals and plants.

The theory of organic evolution put forward by Lamarck in 1809 was based on two laws: (1) **the law of use and disuse;** (2) **the law of inheritance of acquired characters.**

The law of use and disuse suggested that the frequent and sustained use of any organ by an animal during its lifetime would lead to an enlargement or development of that organ. Conversely, it maintained that the lack of use of any organ would lead to its weakening and eventual disappearance.

Lamarck's second law suggested that the development or neglect of any organ by an animal will affect the size of that organ in the offspring. Thus, to take an example, Lamarck's theory would suggest that the long neck of the giraffe had evolved because the giraffe's ancestors had stretched their necks in order to reach the juicy leaves on the higher branches of trees, and had thus passed on their acquired length of neck to their descendants.

Darwin's Theory. Charles Darwin (1809–82) (Plate 30) was the son and grandson of medical men. When Darwin studied at Edinburgh he contemplated a medical career, but later, when he went to Cambridge to study, he decided to enter the Church. This indecision, together with the poor health which held Darwin back throughout his life, resulted in an undistinguished university career.

While at Cambridge, Darwin formed a firm friendship with the professor of botany, who persuaded him to study geology, and later, in 1831, obtained for him a post on the exploring ship *Beagle.* On this voyage Darwin accumulated a great store of observations, which he published in 1835. In his own words, written in old age, "This voyage has been the most important event of my life. I owe to it the real training of my mind."

While on this voyage in the *Beagle*, Darwin was greatly struck by the distribution of animals and plants in South America and near-by islands, and its relation to the forms found as fossils in rock formations there. He perceived the need for a theory of evolution in which the evolution of present-day animals from the simpler types which were present in past ages would be explained; the results of such evolution were evident; all that he required was an explanation of the mechanism whereby it might have occurred. In 1838 he read *Essay on Population*, by Malthus, a book which emphasized the constant struggle for existence between living things. Inspired by this conception, Darwin founded on it his theory of the origin and evolution of species. Simultaneously, another naturalist and explorer, **Alfred Russel Wallace** (1823–1913), had reached similar conclusions, and the work of these two men was first published in 1858 as a joint essay.

Darwin's theory was founded on three sets of facts: (1) **variation,** (2) **inheritance,** (3) **natural selection,** which were supported by a considerable number of personal observations.

Briefly, Darwin's theory suggested that among large numbers of individuals of any one species we find considerable **variation;** for example, while there may be an average height for particular species, some individuals will be tall and others short. Darwin did not attempt to explain the origin of such variations, but believed that they arose by chance. Some of them, he argued, would be advantageous to the individuals possessing them, while others might be harmful.

Darwin then suggested that there is a constant **struggle for existence** in nature, and that those individuals that are best suited to their surroundings will tend to survive rather than their weaker or otherwise handicapped brothers. Therefore, Darwin said, there will be a **survival of the fittest.** Assuming that the variations which help the animals in their fight for survival are inherited by the offspring, we can see how helpful variations might become incorporated in a species, by means of the selection

and preservation by nature of those animals in which these variations were present.

The 'survival of the fittest' did not suggest merely that the healthier animals or plants survived, but rather that those individuals which were best suited to their surroundings were preserved. For example, we find that many races of beetles which live on oceanic islands have considerably shorter wings than their relations which live on the mainland. Darwin's theory explains this fact by suggesting that from time to time long-winged forms have been present in the race, but that these, being accustomed to flying at fair altitudes, have been carried out to sea by the sudden and violent gales which sweep over such islands, while the weaker-winged forms have remained on the islands and produced short-winged offspring.

The long neck of the giraffe can be explained on Darwin's theory by supposing that among the ancestors of the giraffe there were many that had exceptionally long necks, and that these had a greater chance of survival than their shorter-necked relations, thus remaining to produce long-necked offspring.

Comparison between the Theories of Darwin and Lamarck. The theories of evolution of both Darwin and Lamarck maintained that variation (in size, shape, colour, etc.) must occur in any species of animal or plant, though they differed in their explanation of such variation. Thus Lamarck suggested that variation was achieved by the conscious striving of many individuals, and was passed on by them to their offspring; Darwin believed that variations, good and bad, appeared by chance in relatively few individuals. If the variation was advantageous the organism possessing it had a greater chance of survival, but a harmful variation lessened the chance of survival of an organism possessing it.

The theories of both Darwin and Lamarck required that any variation in an organism should be inherited by its offspring. Since the evolution theories were published, the study of heredity has shown that this is so. It has also shown that variations would appear to be spontaneous and accidental, and has in other ways suggested that Darwin's is the more acceptable of the two evolutionary theories. Nevertheless, it is possible that Darwin's theory may be considerably modified by further discoveries, and it is well to remember that Darwin himself wrote in the introduction to his theory "I am convinced that natural

selection has been the main, but not the exclusive, means of modification."

Present-day Evolution. The study of evolution in the past raises the question of whether we can detect instances of evolution proceeding during the present time. There is evidence that in one group at least we may observe evolutionary changes which have occurred during living memory. During the past seventy years or thereabouts certain species of moth in industrial areas have evolved a black colouration. The earliest known case of such **industrial melanism,** as it is called, was provided by the moth species *Biston betularia*, in which a black form was discovered at Manchester in 1850. This black variety has by now almost entirely replaced the paler form in industrial areas in England and elsewhere (Plate 32). Another and comparable example of a like change is given by the moth species *Cleora repandata*, in which the pale form was the only one known in industrial areas up till 1850. To-day it has been almost entirely superseded in these districts by the black variety *carbonaria*. Some thirty years ago the pale and the dark forms were found there in approximately equal numbers.

Melanic variation is known to occur fairly frequently in moths and in some butterflies, and it seems that in certain cases at least the melanic variations are hardier than their paler counterparts. However, in country districts their dark colour probably renders them very conspicuous and therefore liable to attack by birds. In industrial areas the abundance of soot provides a background in which they are less noticeable, and so their pronounced vitality and their protective colour allows them a greater chance of survival. This evolution of an animal species in relation to its environment is of particular interest as representing one of the few evolutionary changes ever witnessed in nature, and undoubtedly a fairly considerable one.

4. The Origin of Life

The theories of evolution suggest that the first form of life to appear on the earth must have been a small and very simple organism, but they do not attempt to explain how the first living thing can have been formed from non-living matter. Scientists cannot create living matter, and our present state of knowledge allows only uncertain speculation on the origin of life. Nevertheless, certain facts must have an important bearing on the subject.

Pasteur's work on bacteria showed that there is no evidence that living things arise spontaneously from non-living matter under the conditions which we find on the earth to-day. It seems improbable that life, as we know it, could travel through outer space to our planet and exist. We are therefore forced to conclude that life must have arisen in the past on our planet.

A study of the simplest forms of life does not solve the problem of its origin. Even the bodies of bacteria, which are so small that they cannot be seen by the naked eye, are yet so complex that they are unlikely to have been formed by the chance collection of non-living chemicals. The ultra-filterable viruses are still smaller than bacteria, and seem to be on the borderline between living and non-living material, yet these organisms will only exhibit the functions of life when they are associated with other living things. We can therefore proceed no further in our speculations. By determining exactly what features of their surroundings enable the ultra-filterable viruses to exhibit the functions of life, we may advance nearer to a plausible theory of the origin of living from non-living matter.

SUMMARY

(1) There is abundant evidence that all living things are related to one another, and that they are the descendants of one common ancestor. The evidence is mainly derived from the studies of comparative anatomy, classification, embryology, geology, inheritance, and the geographical distribution of animals and plants.

(2) Two great theories of evolution were put forward by Lamarck and Darwin respectively. Lamarck's theory suggested that the activities of a living thing will influence its structure, and any such modifications will be inherited by the offspring. Darwin's theory of natural selection supposed that heritable variations in structure arise by chance, and are preserved in the race if they confer any benefit on their possessors.

SUGGESTIONS FOR HOME STUDY

(1) Explain how and why the animals and plants on oceanic islands differ from the forms found on islands near the mainland.

(2) Compare the theories of Darwin and Lamarck. What evidence would you look for in support of either theory?

CHAPTER XXVIII

THE STUDY OF HEREDITY[1]

Men are generally more careful of the breed of their horses and dogs than of their children.

WILLIAM PENN, *Reflections and Maxims*, Part 1, No. 85

1. FAMILY LIKENESS

CHILDREN very often resemble their parents in their appearance, their talents, and their tastes. It is not unusual for a child to inherit the hair-colour of his father, or the height of his mother, and in other ways to resemble both parents. There is also evidence that mental characteristics may be inherited; the families of Darwin and Huxley provide striking examples of a taste and aptitude for science and letters which has persisted through many generations.

Genetics (Gk., *genesis*, descent), the science of heredity, seeks to discover the mechanism whereby qualities are inherited from parents to offspring, and attempts to predict the outcome of particular matings in certain animal and plant species. Genetics is a comparatively recent science, and as yet we know little about heredity in man. Results of great practical value to breeders of domestic animals and cultivated plants have, however, been obtained. Breeders generally attempt to accentuate the good qualities of domestic breeds, such as weight and appearance or milk-production in animals and colour and size in plants, and, if possible, by carefully selected matings, to combine with these features an adaptability to certain surroundings and an immunity to particular diseases.

The results of the early attempts of plant-breeders to produce new breeds by selective breeding were encouraging, but at times unpredictable. Their experiments were mainly directed at the production of hitherto unknown breeds by mating together two unlike forms of plant. Thus, for instance, a horticulturist named Fairchild succeeded, during the latter half of the seventeenth

[1] The science of heredity is a relatively recent and complex science, yet a book of this type would be incomplete without some mention of the principles which underlie the science of breeding, and the study of inheritance. The reader should realize, however, that a chapter of this size can only present a superficial account of this very intricate science.

century, in producing a new plant breed by fertilizing the ovules of a carnation with the pollen of a 'sweet-william' flower. The seed derived from this experiment developed to form a new plant breed, which was intermediate in character between its two parents. Such new breeds produced by the union of unlike parents are known as **hybrids**.

Many new breeds of apples, roses, and other garden plants were developed by those horticulturists who followed the example of Fairchild. But the new breeds thus produced were unsatisfactory in some respects. In many cases these hybrids did not themselves produce fertile seeds, and could therefore only be propagated by cuttings, grafts, or some other means of vegetative reproduction. Those hybrids which did bring fertile seeds did not always produce offspring like themselves. In many cases the seeds of hybrids developed into plants which resembled one of the grandparents, and so the features of the hybrid parent were lost.

The early experiments on animal-breeding were aimed rather at the improvement of existing stock than at the production of new breeds. In the latter half of the eighteenth century a practical farmer named Bakewell sought to improve the quality of cattle by selective breeding between individuals of exceptional weight and flesh quality, and in this he achieved considerable success. Breeders everywhere followed his example, with a consequent improvement in the domestic cattle of Britain and Europe. There is no doubt that these experiments of Bakewell and his contemporaries were accompanied by an improvement in the conditions under which the cattle lived, and it is therefore difficult for us to judge to what extent the improvement in domestic cattle at that time was the result of selective breeding, since the relative importance of the environment needs to be taken into consideration.

The experiments of early plant and animal breeders are of interest because they stimulated research on the problems of hybridization and the relative importance of heredity and the environment, so laying the foundations for the science of genetics. The early breeders were faced by two main problems. First, they had no reliable means of estimating the relative influence of heredity and environment (*i.e.*, ancestry and upbringing) in judging the value of any stock. Secondly, the instability of hybrid breeds rendered them difficult to perpetuate, except by vegetative propagation.

Subsequent researches on these problems of inheritance have made the study of breeding a more exact science.

2. Mendel and the Science of Heredity

During the early part of the nineteenth century many investigators studied the problem of the instability of hybrids. They found that certain types of inheritance were frequent in particular hybrid matings, but their experiments were not carried out on a sufficiently large scale to allow them to predict the proportions of the various offspring which were obtained by the mating of hybrids.

The first large-scale and carefully controlled experiments on heredity in plants were carried out by an Austrian monk named Gregor Johann Mendel (1822–84) at the Abbey of Brünn, in Central Europe.

Mendel's experiments were carried out on that sweet-pea which belongs to the genus Pisum. This had proved to be suitable for the work for the following reasons: (1) there is a number of variations, which are easily distinguished by differences in height, shape and colour of seeds, and other features; (2) it is easily kept, and is self-pollinated, while the hybrids yield fertile offspring.

In the first experiment which Mendel describes, he chose the form and colour of the seed as the feature to be studied. One variation of plant normally bore only round, or nearly round, seeds, while in another variation the seeds had wrinkled coats. Mendel crossed[1] these two variations of plant and observed that *round seeds only* were produced, irrespective of whether the pollen was derived from the 'round' or 'wrinkled' parent.

Continuing this experiment, Mendel then allowed the hybrid plants which formed from these round seeds to self-fertilize, and thereby subsequently to produce seeds. From 253 hybrid plants 5474 round seeds and 1850 wrinkled seeds were obtained, a ratio of 2·96 : 1. Further experiments showed that about one-third of the round seeds behaved like the original round seeds of the grandparents and produced round-seeded offspring only, while two-thirds resembled those seeds which formed their hybrid parents. It therefore appears that approximately one-half of the offspring of hybrid parents will resemble their parents, while

[1] In genetics selected matings are termed 'crosses.'

the other half will have equal chances of resembling either one or the other grandparent.

It is interesting to note that the F_1 (or first 'filial') generation of the experiment described above resembled the 'round' rather than the 'wrinkled' parent. It seems, therefore, that certain characters are **dominant** to their contrasted counterparts. Thus it appears that roundness in seeds is dominant, while wrinkling in seeds is subordinate, or **recessive.** Mendel found that the numerical proportions which he had noted in his first experiment were repeated in experiments with other contrasted characters.

Dominant Character	Recessive Character	Numbers bearing Dominant Character to that bearing Recessive Character in F_2 Generation	Ratio
Yellow cotyledons	Green cotyledons	6022 : 2001	3·01 : 1
Violet-red flowers	White flowers	705 : 224	3·15 : 1
Long stem	Short stem	787 : 277	2·84 : 1
Inflated pods	Constricted pods	882 : 299	2·95 : 1
Green pods	Yellow pods	428 : 152	2·82 : 1

By means of these experiments on sweet peas Mendel showed that the inheritance of certain characteristics, at least, could be predicted with reasonable accuracy, since the types of offspring of hybrid crosses appeared in definite numerical proportions. The 3 : 1 ratio observed can best be explained by postulating the existence of paired internal factors for the control of any one of the various features of an organism. Thus in Mendel's first experiment we may consider that the 'round' pea plant had the internal

(original parents) → RR (round) X rr (wrinkled)

F_1 Rr (hybrid round) X Rr (*i.e.*, self-pollination)

F_2 RR Rr Rr rr

constitution RR, while the 'wrinkled' pea plant was effected by the paired factors rr. The hybrid seed, which receives factors from both parents, will therefore have the constitution Rr. The 3 : 1 ratio in the F_2 generation can be explained by the diagram

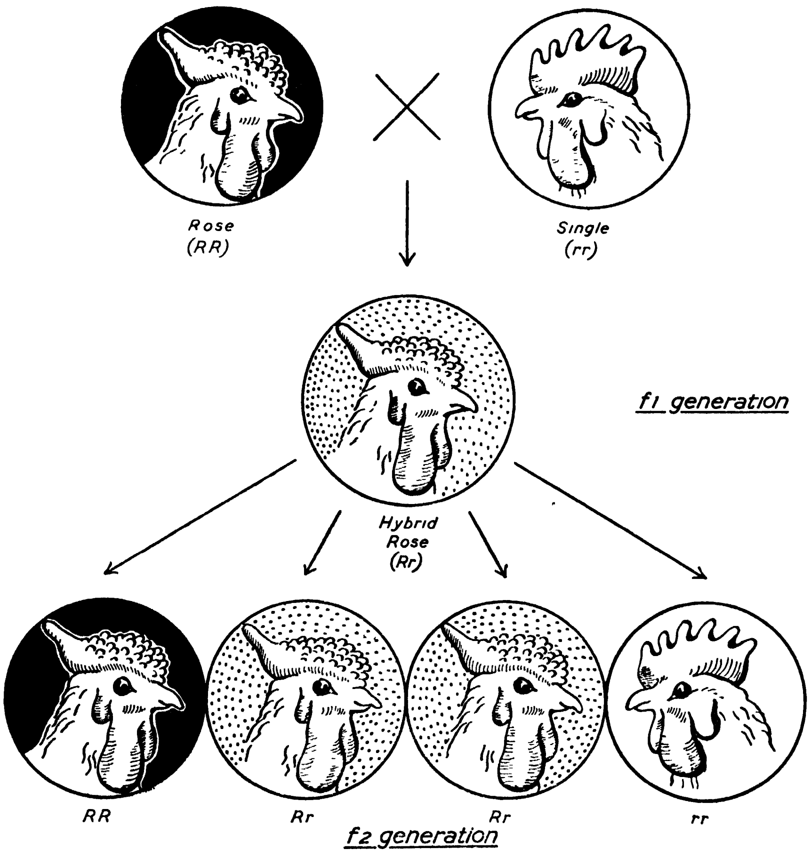

FIG. 141. EFFECT OF BREEDING TOGETHER TWO INDIVIDUALS WITH CONTRASTED CHARACTERISTICS

This diagram shows the offspring (F_1) of a cross between a 'single-comb' and a 'rose-comb' fowl. When two such hybrid offspring are bred together their progeny (F_2) may arrive in the proportions shown. The combs of male birds only are shown for ease in comparison.

shown at page 303, in which we see that the factors Rr must separate independently during the formation of gametes.

An example of inheritance in poultry may serve to emphasize this point. The type of comb known as 'single' in the Leghorn and other Mediterranean breeds of poultry is recessive to the rose comb of the Hamburg and Wyandotte breeds. When the hybrid rose-comb offspring of pure-bred rose-comb and single-

comb birds are crossed we find again the 3 : 1 ratios in the F_2 generation.[1] (See diagram Fig. 141.)

These experiments on hybrids, which form the earlier part of Mendel's work,[2] showed that, in some cases at least, the inheritance of characteristics could best be explained in terms of units called **factors,** which exist in pairs (though not blended) in living organisms. And so the reversion of a hybrid's offspring to the grandparental type can be identified with the behaviour of predictable units. Subsequent research has confirmed Mendel's work, but shows that cases of simple Mendelian inheritance are rare, and are usually complicated by the influence of various modifying conditions.

3. The Extension of Genetics

We owe a great deal of our present knowledge of the principles underlying heredity to the research work which has been carried out in laboratories, using very large numbers of animals. One, a fruit-fly, has proved to be especially suitable for this purpose. This animal, *Drosophila melanogaster*, is easily kept, and is very hardy; it produces many young, and passes through its entire life-cycle in little more than a week. A year's work on Drosophila may reveal facts pertaining to heredity which would have required more than a century of work to obtain if the experiments had been carried out on cattle. Many millions of Drosophila are bred experimentally each year.

Laboratory experiments have established the probable position of the internal factors, the existence of which had been postulated by Mendel. His experiments showed that characteristics of organisms, height or colour for example, seemed to be controlled by pairs of internal factors, and that the gametes contain one component only of each factor-pair. Thus, the hybrid offspring of a red flower and a white flower would seem to contain some factors for redness and an equal number of factors for whiteness. The gametes, however, contain only one factor, so that half the pollen grains would seem to bear the white factor only, while the other half contain only the red factor. We must therefore look

[1] This ratio indicates only the degree of probability that the types will appear in the offspring. It is quite *possible* that, from among a few offspring, no single-comb birds would appear.

[2] Mendel's later work has been modified so greatly by subsequent researches that I have omitted it from this brief survey of heredity.

for some structures which are present singly in the gametes but are found in pairs in the body-cells.

The chromosomes (see p. 171), which can be seen during cell-division, are present in pairs in the body-cells, while their numbers are halved during the formation of gametes. Drosophila has only four chromosome pairs, and these are especially large in the cells of the salivary glands of this animal. Research work on Drosophila

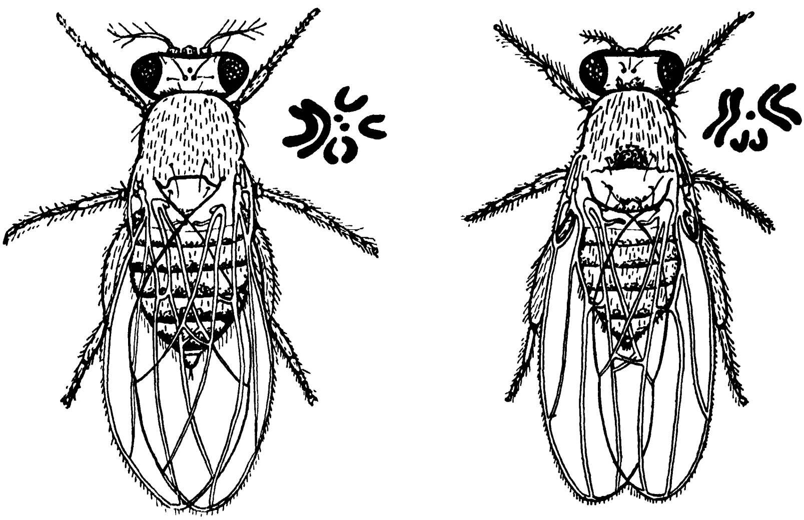

FIG. 142. RELATIONSHIP BETWEEN CHROMOSOMES AND EXTERNAL FEATURES

On the left is shown a normal female of *Drosophila melanogaster*, and on the right an individual in which one of the smallest chromosomes is missing. Its loss causes differences of size, shape, and colour. The chromosomes of each fly are shown beside it. Redrawn after Morgan.

leaves little doubt that the hereditary factors, or **genes,** are situated on the chromosomes, and work on other animals and plants supports this view.

Research work on chromosomes has shown also that sex is a quality that is inherited. The genes controlling sex are situated on a special pair of chromosomes, called sex-chromosomes. In women these chromosomes are similar to one another, and are denoted by the term XX; men, on the other hand, possess an unlike pair of sex chromosomes. One of these is an X chromosome, which is derived from the mother, and the other is a Y chromosome, which is received from the father. During the formation of eggs and sperms all the eggs receive one X chromosome, but only half the sperms contain an X chromosome; the other half

contain a Y chromosome. And so the chances should be equal as to whether an X-bearing or a Y-bearing sperm will meet an egg and produce a female or a male respectively.

Some genes are carried on the sex chromosomes, and so the characters they control may be associated with one sex only. For instance, in cats the genes for black and yellow colours are carried on the X chromosomes. The Y chromosome does not bear these genes. Therefore a tom-cat can be either black or yellow only, but a female can get both genes, and so be tortoiseshell in colour. If a tortoiseshell female is mated to a black tom-cat half the female offspring will be tortoiseshell and half will be black; half the males will be black and half will be yellow.

Sex-linkage of genes, as it is called, is used by poultry breeders in order to detect the sex of young chickens. In birds the male has XX sex chromosomes, the female bears XY sex chromosomes. In the Light Sussex breed a gene on the X chromosomes stops the formation of yellow pigment in the feathers. If, therefore, we mate a Light Sussex hen with a Rhode Island Red cock, the young cockerels get this gene, and are therefore white, but the pullets do not get it, and are therefore yellow. The sexes can thus be detected at the moment of hatching.

Hæmophilia is a disease in which the blood does not easily clot on an open wound, which may result in the sufferer bleeding to death. The disease is due to the presence of an unusual gene on an X chromosome. Women seldom suffer from the disease because the effects of the gene for hæmophilia are generally masked by the other gene of the pair, on the other X chromosome. Men, however, have no gene on the Y chromosome to counterbalance the gene for hæmophilia if it is present, and so they may suffer from the disease.

Queen Victoria was a carrier of a gene for hæmophilia. One of her sons, Prince Leopold, was hæmophilic, but King Edward VII was not, and so no hæmophilia is present in the British Royal Family. Two of Queen Victoria's granddaughters inherited the tendency to hæmophilia. One married Tsar Nicholas of Russia, the other married King Alfonso of Spain. In both cases hæmophilic sons were born.

Work on Drosophila also clarified a problem which had been observed by many animal and plant breeders, namely, the sudden appearance of variations in what had hitherto been regarded as 'pure-line' stock. For instance, a red-eyed race would

unexpectedly produce white-eyed individuals, or long-winged flies would produce offspring without wings. Sudden inherited changes in the genes are known as **mutations** (L., *mutare:* to change). Clearly detectable mutations were found in Drosophila to occur once in every 50,000 to 100,000 individuals. The result of mating a form with mutant characters with a normal individual has been studied. In most cases the corresponding gene of the normal individual seems to be dominant to the mutant gene, which thus rarely appears in succeeding generations.

Geneticists have also been especially occupied with two other important problems, namely (*a*) the relative effects of heredity and the external environment in determining the characteristics of any individual, and (*b*) the influence of the other genes on any particular gene.

There is evidence that the ancestry of an organism and its surroundings interact to determine the features of that organism. Thus in one flower species, one variety (*Primula sinensis rubra*) has red flowers if grown at a temperature of 15°–20° C., but forms white flowers if grown at 30°–35° C. Another variety (*Primula sinensis alba*) forms white flowers at all temperatures. It is clear, therefore, from these and other observations, that the action of the genes may in some cases be modified by the organism's environment.

The possible multiple effects of genes and the interaction between various genes adds further complexity to the problems of genetics. Thus in Drosophila the gene for white eye colour also affects the colour of the testis sheath and the shape of one of the reproductive organs. Research work has also shown that the action of any gene may be affected by the other genes in the same individual. Results such as these emphasize the complexity of genetics, and explain why so many problems are encountered in the practical breeding of domestic animals and plants.

4. The Application of Genetics

The science of heredity still presents innumerable problems and opportunities for further research. Nevertheless, many of the experimental results obtained in laboratories have assisted the work of animal and plant breeders.

Certain varieties of animals and plant species are relatively insusceptible to diseases which may prove fatal to the normal type

of the species. For example, Algerian sheep are immune to anthrax, the West African Negro does not suffer from yellow fever, while, in contrast, measles is often a fatal disease to American Red Indians. In some cases carefully selected matings have enabled plant and animal breeders to produce types which combine the commercial advantages of one variety with the immunity to particular diseases that has been inherited from the other parent.

The wheats known as 'Little Joss' and 'Yeoman,' which are widely grown in the British Isles, were developed by Professor Sir Rowland Biffen, of Cambridge, in the course of scientifically controlled breeding experiments. 'Little Joss' combines a resistance to the wheat-rust fungus (*Puccinia graminis*) with a high yield of grain and straw. 'Yeoman' wheat combines a high yield with a type of grain which is very suitable for milling purposes.

In Java the sugar-cane industry was recently threatened by a virus disease, but it has been restored and improved by selected matings between the cultivated type and a local wild type, which was immune to the virus disease. In this way a new immune breed with a high yield was achieved.

The account given earlier in this book (p. 263) of the breeding experiments intended to combat the attacks of the potato-blight fungus indicated some of the difficulties which may be encountered by the breeders of domestic animals and plants. The advances in genetics in the past few decades, however, give good reason for the expectation that genetics will in the future promote a very considerable improvement in the domestic stocks of mankind.

Our knowledge of human inheritance is bound to be restricted by the difficulties of experimental work. The inheritance of a few marked traits has been studied, and it has been shown that a number of mental and physical defects are inherited. Such are hæmophilia (p. 307), various forms of mental deficiency, and many minor abnormalities, as, for instance, brachydactyly, an absence of one of the joints of the fingers. Most of these abnormalities are controlled by recessive genes, and their effect is generally swamped by a dominant gene in the same factor pair. In consequence, these and other hereditary diseases are relatively rare in occurrence. Yet the possibility of masked recessive genes of this nature is always present, and it is on this account that marriages between first cousins (especially if there is any indication of hereditary diseases in the family) are somewhat hazardous.

Under normal conditions an individual who possesses a recessive gene for some defect has only about a one-in-seventy chance of marrying another with the same recessive gene, yet if this individual marries his cousin the chances are increased to about one in eight, since there exists this degree of probability that they will both have received the same gene from the same grandparent.

The proved inheritance of certain tragic defects lends support to the view that individuals possessing these abnormalities should not be allowed to rear children. At present medical men can, in certain cases, warn married couples when they have a considerable chance of producing defective children. Perhaps advances in genetics may in the future allow us to compute with even greater accuracy the dangers to the human race if the feeble-minded and other carriers of harmful traits are permitted to bear young.

SUMMARY

(1) Mendel's work suggests that any feature of an organism, say its height or colour, for example, is dependent in the first instance on two factors, one derived from each parent. These factors remain distinct throughout the life of the organism and separate in the formation of gametes, so that for any one feature half the gametes contain the factor derived from the mother while the other half contain the factor derived from the father.

(2) Subsequent research has confirmed Mendel's view, though it has been extended and modified in many respects.

SUGGESTIONS FOR HOME STUDY

(1) Calculate the probable ratio of the offspring of a cross between a hybrid 'single' comb fowl (Ss) with a pure-bred 'rose' comb (SS) fowl.

(2) Compare, in a wide sense, Mendel's work with (*a*) the Cell Theory, (*b*) the Atomic Theory in chemistry, indicating how the definition of units led to great exactitude.

A LIST OF SOME INHERITED CHARACTERS IN MAN

THE list given below has been derived from a more complete list in *Genetics for Medical Students*, by E. B. Ford (Methuen, 1942). The author of that book recommends "Caution must be exercised in using this list. In some cases environmental agencies may modify the expression of a gene." Other complications may also operate in the control of the characters mentioned.

(*A*) RECESSIVE GENES

Red hair. (Probably some complications.)
Blue or grey eyes. (Probably some complications.)
Albinism.
Amaurotic idiocy.
Deaf-mutism.
Red-green colour-blindness. (Sex-linked.)[1]
Total colour-blindness. (Partial sex-linkage.)
Hare-lip and cleft palate. (Partial sex-linkage.)

(*B*) DOMINANT GENES

Auditory nerve atrophy.
Congenital cataract.
Diabetes insipidus.
Huntington's Chorea.
Absence of upper lateral incisors.
Piebalding.
Split foot.
Supernumerary teeth.
Woolly hair (among Europeans).

[1] Sex-linked features are usually found in one sex only.

BOOKS FOR FURTHER READING

I HAVE included in the following list a number of books which provide more detailed accounts of the topics mentioned in the preceding chapters. The list is not intended to be a comprehensive bibliography. Rather, it is an attempt to help any reader whose curiosity has been roused by any of the material included in this book. Many books which the teacher or the pupil may find valuable as works of reference are also included. Wherever possible, inexpensive and recently published books have been chosen.

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THE HOUSE-FLY: A REPRESENTATIVE ANIMAL

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THE STUDY OF HEREDITY

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CHAPTER II

THE HOUSE-FLY: A REPRESENTATIVE ANIMAL

(1) The Adult Fly

Obtain some living house-flies. Keep them under an inverted bell-jar and observe their method of feeding. Make a careful labelled drawing of one, and identify the species to which it belongs.

(2) The Legs of Flies

Examine a leg of a fly under the microscope. Comment on the structure of the foot of the fly.

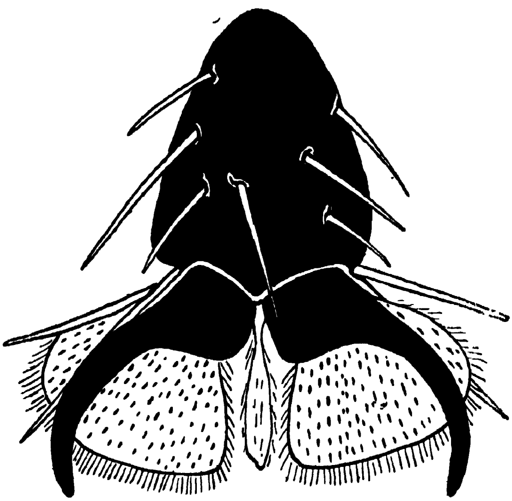

Fig. 143. The 'Foot' of a House-fly, showing the Hooks and Pads

(3) Responses of Fly-larvæ to Light

Blow-fly larvæ can be obtained by leaving the body of a dead bird or other small animal, or some other meat, on a roof in the spring or summer. Blow-flies will lay their eggs in the meat, and after some days larvæ will emerge.

When blow-fly larvæ have been obtained place them on a table in a darkened room. Shine a light on the larvæ from one side, and observe their movement away from the light. Arrange another light also at the side of the table, but at right angles to the first. Switch this on also, and observe the result.

(4) THE DIGESTIVE SYSTEM OF A FLY

By holding a fly larva in a compressorium and examining it under a microscope one may see the rhythmical movements of the digestive system inside the larva. Refer to p. 102 for a description of these peristaltic movements, as they are called.

(5) TRACHEÆ

Tracheæ will be clearly seen in the body of the larva examined in the last experiment.

Small aquatic larvæ of may-flies, gnats, and other insects (*e.g.*, Corethra) also provide suitable objects for study.

CHAPTER III

THE MEADOW BUTTERCUP: A REPRESENTATIVE PLANT

(1) SPECIES OF BUTTERCUP

Collect as many different species of buttercup as you can, and record the differences which you observe.

(2) ROOTS

Carefully dig up a few small plants and wash their roots. Notice how the latter are arranged in the soil. Draw the root-systems in each case. (*E.g.*, consider separately dandelion, creeping buttercup, grass, and wallflower.)

(3) THE BUTTERCUP FLOWER

Make a vertical cut through a buttercup flower, using a clean safety-razor blade. Draw a section of your flower and compare it to Fig. 84.

(4) THE FUNCTION OF POLLEN

Carefully open several flower-buds from buttercup plants. Remove the petals and stamens, using fine forceps. Then cover what remains of the buds with little bags of fine muslin. No pollen will find its way to the stigmas, and therefore no ripe fruits will be formed.

In order to show that this failure of the fruits to develop is due only to lack of pollen, we may, by means of a clean, soft paint-brush, transfer a little pollen from another buttercup flower on to the stigmas of flower-buds from which petals and stamens have been removed. If, as before, we then cover the buds with muslin bags, fruits will now nevertheless form.

(5) Germination of the Bean

Pack some bean seeds in damp moss, laid on wire-netting above a dish of water. Leave in warmth and darkness, and examine daily.

(6) Germination of Cress

Spread some cress seeds evenly on a piece of damp blotting-paper laid in a dish. Leave in warmth and darkness. Examine daily.

(7) Leaf-fall

Gently pull off some leaves of trees in autumn. Notice the smooth leaf-scars, already covered with cork. Compare these results with those obtained from a similar experiment in the summer.

CHAPTER IV

THE COMPOSITION OF LIVING THINGS

(1) Body-cells (Plate 6)

Scrape the inside of your cheek with a finger-nail or a *clean* scalpel. Mount the grey fluid so obtained on a slide in salt solution (0·75 per cent.), and cover with a cover-slip. Examine under the high power of a microscope.

Stain nuclei by putting a few drops of methyl green at the edge of the cover-slip and allowing the stain to soak underneath.

(2) Cells of Plants

Examine (*a*) a leaf of Elodea (Canadian pond weed), (*b*) a moss-leaf, (*c*) skin of a laurel leaf, (*d*) scale of an onion bulb. All should be examined on a slide under the high power.

(3) Living Cells

Kill an earthworm in a solution of 70 per cent. alcohol. Make an opening in the body-wall with scissors, and extract some of the fluid in the body-cavity with a hypodermic syringe. Place on a slide and examine under the high power of a microscope. Observe cells, nuclei, and movements of protoplasm.

(4) Blood-cells

See Experiments 4 and 5, Chapter XI.

(5) Tissues

Examine prepared slides of a frog's intestine, a nerve, blood, and a plant stem. Describe the many different types of cells that you find.

CHAPTER V

CLASSIFICATION

(1) Inter-specific Dissimilarities

Collect grasses and record their differences in appearance and structure. Examine leaves of *Ranunculus acris* and *Ranunculus repens* (p. 37).

Examine wings of *Musca domestica* and *Fannia canicularis* (p. 28 and Fig. 12).

(2) Weight of Beans

Weigh a number of freshly gathered beans or peas. Plot the numbers of each weight as a graph.

(3) Differences between Flowers

Examine three flowers and note all the differences that you can.

Suggested types: wallflower, sweetpea, buttercup, daisy.

CHAPTER VI

HOW PLANTS FEED

EXPERIMENTS ON PLANT NUTRITION

(1) The Necessity for Certain Elements (Plate 4)

Take a number of gas-jars and cover them with black paper to exclude light. Fit each with a cork pierced by three holes. Insert short lengths of glass tubing in two holes, leaving the central hole for the plant. Fill the jars as follows:

Jar 1: Full Solution

Potassium nitrate, 2 grammes.
Magnesium sulphate, 0·5 gramme.
Calcium sulphate, 0·5 gramme.
Ferric phosphate, 0·5 gramme.
The whole dissolved in two litres of glass-distilled water.

Jar 2: Nitrogen-deficient Solution

Make a solution similar to that in Jar 1, but substitute potassium sulphate for potassium nitrate.

Jar 3: Sulphur-deficient Solution

As for Jar 1, but substitute magnesium nitrate for magnesium sulphate, and calcium nitrate for calcium sulphate.

Jar 4: Phosphorus-deficient Solution

As in Jar 1, but substitute ferric sulphate for ferric phosphate.

Jar 5: Calcium-deficient Solution

As in Jar 1, but use magnesium nitrate in place of calcium sulphate.

Jar 6: Potassium-deficient Solution

As in Jar 1, but substitute sodium nitrate for potassium nitrate.

Jar 7: Totally Deficient Solution

Fill jar with glass-distilled water only.

Young grass seedlings of similar size and age are placed through the central holes in the corks, so that their roots just dip into the water, and are held in position by packing with cotton-wool. The glass tubes, which are also plugged with cotton-wool, serve for the daily aeration of the solutions, and the addition of more distilled water, if needed. After some weeks the plant in the full culture solution should be healthy, while those grown in solutions deficient in certain elements should exhibit a starved and stunted appearance.

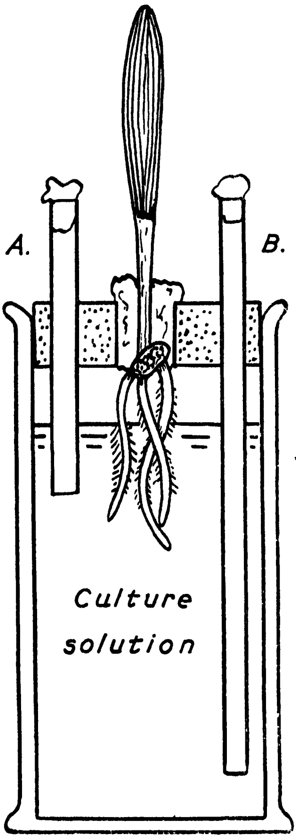

FIG. 144. APPARATUS FOR WATER-CULTURE EXPERIMENTS
Tube *A* is used for renewal of the solution, and tube *B* for the aeration of the solution.

(2) THE NECESSITY FOR CHLOROPHYLL

A leaf of Pelargonium, or of some other plant with variegated leaves, is kept in the dark for twelve hours (in order to remove starch) and is then left in bright light for some hours. Draw the leaf, recording the position of the coloured portions. Dip the leaf in boiling water, and then decolourize it by placing it in a warm solution of 70 per cent. alcohol. Wash the leaf, and then immerse it in a solution of iodine in potassium iodide. Compare those portions stained dark blue with those marked in your drawing. Starch, which stains blue in the presence of iodine, is only found where chlorophyll is developed.

(3) TO SHOW THAT THE CARBON DIOXIDE IN THE ATMOSPHERE IS NEEDED FOR STARCH-FORMATION

(*a*) Smear some vaseline over both sides of a green leaf on a plant. Leave for some days, remove the vaseline, and then test for starch. Little or no starch will be found.

(*b*) In order to show that it is CO_2 which is the necessary

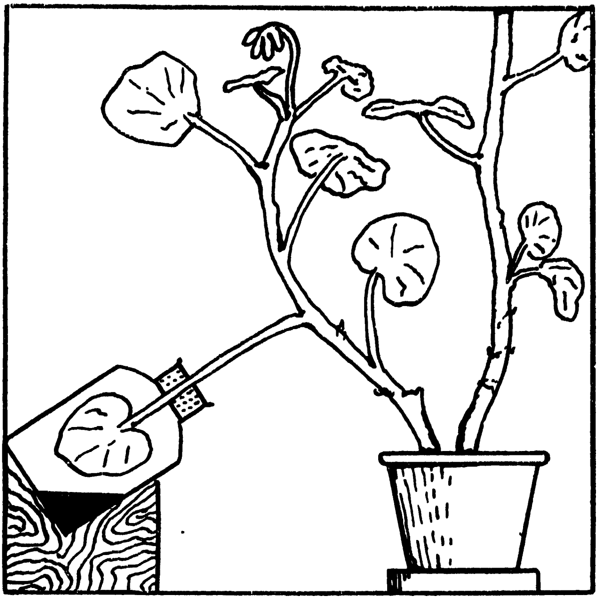

FIG. 145. EXPERIMENT TO SHOW THAT CARBON DIOXIDE IS NEEDED FOR STARCH-FORMATION IN A LEAF

The apparatus should be exposed to strong sunlight.

factor for photosynthesis, place two plants under separate bell-jars. In one bell-jar place some caustic potash (potassium hydroxide), which will absorb the CO_2, and allow air to enter this jar only through soda-lime, which also absorbs CO_2. The other jar has free access to the air. After some days examine the plants and test their leaves for starch.

(*c*) Take a starch-free plant which has been in darknes for twelve hours and place one of its leaves in a jar containing caustic potash (Fig. 145). After exposure to light for some hourstess the leaves, as above, for starch.

(4) TO SHOW THAT WATER IS IMPORTANT FOR STARCH-FORMATION

Place a plant in the dark for forty-eight hours, thus ensuring that there is little or no starch in the leaves. Having removed

the leaves, place one in water, another in a dry container, and put both in light. After six or eight hours test for starch.

(5) The Release of Oxygen during Photosynthesis

Set up the apparatus shown in Fig. 146. Canadian pondweed (*Elodea canadensis*) or Water Crowfoot (*Ranunculus aquatilis*) are

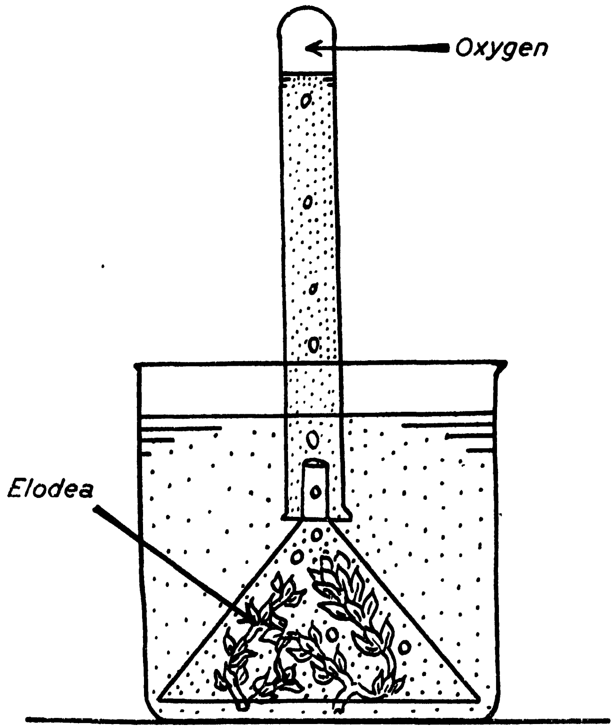

Fig. 146. Experiment to show that Oxygen is given off by a Water-plant in Light

suitable water-plants. Bubble carbon dioxide from a Kipp's apparatus into the water. Leave the apparatus in sunlight. Bubbles will rise from the plant and replace water in the test-tube. When enough gas has collected in the tube, test for oxygen; the gas should rekindle a glowing splint.

Repeat the experiment, having first boiled the water to drive off the carbon dioxide. Observe the result.

(6) Stomata

Strip the outer layer off a leaf of bean, iris, or narcissus. Mount this in water and examine under the microscope.

(7) AIR IN LEAVES

Take some privet leaves that are without scars. Seal the ends of the leaf-stalks with vaseline or plasticine. If a leaf is then immersed in water heated almost to boiling-point bubbles will appear on the under-surface of the leaf as air in the leaf is expanded by the heat and escapes through stomata.

EXPERIMENTS ON TRANSPIRATION

(8) TO SHOW THAT WATER IS GIVEN OFF BY A PLANT AS IT TRANSPIRES

Take a potted plant and cover it with a bell-jar. Place a pot of earth under a similar bell-jar. Note that after a short time drops of water will appear on the inside surface of the first bell-jar. Water-vapour given off by the plant has condensed on the cold surfaces in the inside of the bell-jar.

(9) TO MEASURE THE RATE OF TRANSPIRATION

Set up the apparatus shown in the accompanying figure. As the branch transpires it will draw water from the jar in which

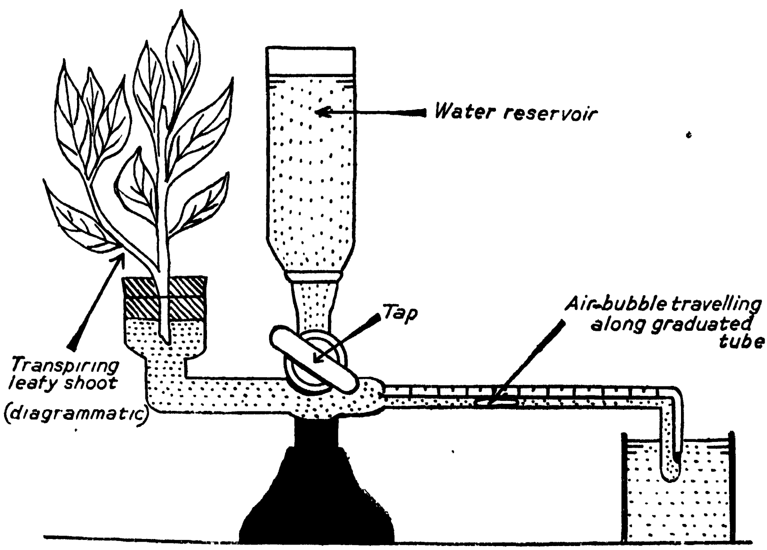

FIG. 147. A POTOMETER
An apparatus used to show that a leafy branch transpires.

its cut end is immersed, and consequently water will pass along the capillary tube. If the other end of the capillary tube is raised from the beaker for a few seconds a bubble of air will form, and will be drawn along the tube. The rate of movement of the bubble

will give some indication of the rate of transpiration of the branch. Such an apparatus for measuring the rate of transpiration is called a *potometer*.

(10) To show that Transpiration takes place through Stomata

Smear vaseline on (*a*) the upper surface, (*b*) the lower surface, or (*c*) both surfaces, of the leaves of the transpiring branch in Experiment 9 above. Note the effects on the normal rate of transpiration.

(11) Root-hairs

Grow cress seedlings between sheets of wet blotting-paper. Examine the root-hairs.

CHAPTER VII

THE SOIL AND PLANT GROWTH

(1) The Water-content of Soil

First weigh a sample of fresh soil, then dry it at a temperature of 100° C. until its weight is constant. The difference between the first and final weights will tell us the amount of water in the sample.

(2) The Humus-content of Soil

Take the dry soil left from Experiment 1 above and heat it strongly in a crucible until it turns red. Weigh again and note the loss of weight; this loss consists mainly of humus.

(3) The Air-content of Soil

Place some fresh soil in a measuring cylinder, thus recording its volume. Pour on it an equal quantity of water, and stir. Water will replace the air between the soil particles, and the total volume will be less than the sum of the original volumes of soil and water; the difference in volume will represent the volume of air in the original sample.

(4) The Influence of Lime on Soil

Fill two jars with water and add a little clay to each. Stir so as to make a muddy liquid, and then add a little lime to one jar. Leave for a short time and note the result, comparing it with that in the jar containing clay only.

(5) Examination of Root-bacteria (Plate 6)

Carefully dig up, wash, and examine the roots of a clover, lupin, pea, or bean plant, which is growing in ordinary garden soil. Notice the root-nodules. Crush a small portion of a root-nodule on a slide and examine under the high power of a microscope; note the bacteria.

(6) Worms and Soil

Take a glass jam-jar and in the bottom put some stones, afterwards adding alternate layers of damp sand and soil. Cover the top layer with leaves, place a few worms inside the jar, and cover the top with cardboard. After some days you will see that the worms have burrowed, started to consume the leaves, and mixed the sand and soil.

CHAPTERS VIII and IX

FOOD AND DIGESTION

(1) An Analysis of Food

(*a*) Carbohydrates

Many carbohydrates are soluble in water; a few are insoluble, or only slightly soluble.

Sugars. Glucose (grape sugar), sucrose (cane sugar), and maltose (malt sugar) are found in food materials. These sugars are soluble in water. Glucose and maltose turn brown when heated with caustic soda or caustic potash, while sucrose does not.

Starches. Starch is to be found as food reserves in plants. The tubers of potatoes in plants contain much starch. A compound called glycogen, allied to starch, is to be found in the livers of animals. Starch is not soluble in water.

Tests by Means of Colour Reactions

Sugar. Add glucose to equal quantities of Fehling's solutions A and B. On warming the resulting solution, an orange precipitate will appear. Sucrose will not give a precipitate with Fehling's solution unless it is first heated with dilute sulphuric acid, which converts it to glucose.

Starch. Shake up powdered starch in water and add iodine solution. A blue colour will appear, which will disappear on boiling and reappear on cooling.

(*b*) Proteins

Many proteins are insoluble in water, while others are soluble.

When proteins are heated they coagulate (*i.e.*, form a hard jelly); this coagulation is irreversible.

White of egg belongs to a type of protein called an albumin.

Colour Test

(1) Add five drops of strong nitric acid to five millilitres of white of egg. A white precipitate will be formed which on boiling turns yellow. Allow this to cool, and add three drops of ammonia (specific gravity 0·880). A bright orange colour indicates protein.

(2) Add four drops of Millon's reagent to five millilitres of white of egg and warm. A red colour indicates protein.

(*c*) Fats and Oils

Fats and oils are generally insoluble in water, but soluble in ether or chloroform.

Colour Reactions

(1) Take some olive-oil and smear it on a slide. Expose the slide to fumes of 2 per cent. osmic acid, and note black colouration.

(2) As above, but dip slide into Sudan 3· solution, and note red colouration.

(2) THE ACTIONS OF DIGESTIVE JUICES

The Mouth. Saliva, which contains the enzyme ptyalin, is formed in the mouth. Spit into a test-tube, and then dilute the saliva with ten times its volume of distilled water. Take ten millilitres of this solution and add two millilitres of 3 per cent. starch solution. Place the test-tube in a beaker of warm water, heated to about 37° C. Test after two minutes with Fehling's solution. Note by the red colouration present that starch has been converted into sugar.

Repeat, having first boiled the saliva solution. Note that no digestion occurs; the enzyme has been destroyed.

The Stomach. Obtain a commercial preparation of pepsin. Add this to a small piece of boiled white of egg and leave overnight. Observe that the insoluble protein has been converted to soluble peptones.

The Pancreas. Commercial pancreatic extracts will convert starch into sugar. Pancreatic juice also converts small pieces of meat and white of egg to soluble peptones. Add small pieces of meat or egg to a test-tube of pancreatic fluid and leave overnight. Observe the result next day.

(3) Digestion in the Earthworm

Open an earthworm by means of a single longitudinal cut down the dorsal side. Notice the digestive system. Examine a diagram of the digestive system of a worm in a more advanced text-book. Draw a labelled diagram of your dissection.

(4) Digestion in the Frog

Examine a dissected frog and note the digestive system. Compare it with those of a worm and a man.

CHAPTER X

RESPIRATION

(1) Carbon Dioxide and Food Combustion

Burn a little sugar in a gas-jar in which there is a test-tube containing lime-water. Notice that CO_2 is given off by the burning sugar.

(2) Respiration and Heat Production

Experiment at p. 21.

(3) Water in Breath

(*a*) Cobalt chloride is blue when dry, but pink when moist Soak filter-papers in a 5 per cent. solution of cobalt chloride and then dry. Breathe on one of these papers and observe the result.

(*b*) Breathe on to a mirror and observe the condensation of water in the breath, which forms as droplets on the mirror.

(4) Lung Capacity

Ascertain with a tape-measure the circumference of your chest and those of your friends. Measure the expansion when you breathe deeply.

Record the approximate volume of your lungs by taking a deep breath and then breathing out through a tube so arranged that the other end projects under the edge of an inverted bell-jar filled with water and standing in a dish containing water. The volume of water displaced will approximate to your lung capacity.

Is there a relation between the degree of chest expansion and that of lung capacity?

(5) Breathing-tubes in Insects

Place a small aquatic larva of a may-fly or gnat on a slide, and cover with cover-slip. Observe tracheæ.

Alternatively, remove tissues from body of cockroach and look for tracheæ under a microscope.

Look for spiracles on the body of a caterpillar.

CHAPTER XI

TRANSPORT

(1) Conducting Tissues of Stems

Examine prepared slides of transverse and longitudinal sections of stems—*e.g.*, buttercup, oak. Compare with Plate 12.

(2) Conducting Tissues in Leaves

Place some leaves in water and leave them for some weeks, until all except the 'veins' have rotted away. Alternatively, look in autumn for rotted leaves in pools of water.

(3) Conducting Tissues in Flowers

Leave some cut shoots of white phlox or of narcissus with their cut ends immersed in diluted red ink. Observe the veins in the petals, reddened by the ink which is conducted by the vascular tissue.

(4) Blood-structure in the Frog

Smear a drop of frog's blood on a slide; cover with a cover-slip. Examine under microscope. Compare with Plate 9.

Put a drop of methyl green or methyl violet at the edge of the cover-slip. It will soak underneath and stain the nuclei of blood-corpuscles. Compare these last with those in human blood.

(5) Human Blood-structure

With a sterilized needle prick your finger just behind the nail. Smear the drop of blood which emerges on a cover-slip, and place this rapidly, blood side downward, on a slide. Examine.

The needle may be sterilized by heating it to a red heat in a bunsen flame.

The addition of a solution of salt will prevent the corpuscles clinging together. The proportions used should be eight grammes of salt to one litre of water.

Stain as in Experiment 4. What do you observe?

(6) Chemical Changes in Blood

Put a few drops of fresh blood in a test-tube. Add first a little

distilled water, and then a few grains of powdered sodium hydrosulphite.

This chemical removes the oxygen from the blood, which then turns purple. Shake the test-tube, and note that the scarlet colour is restored. Why?

(7) THE HEART-BEAT

Discover the rate of your heart-beat by feeling your pulse, which is situated on the inner side of the wrist. Lie down, stand up, and take exercise, and note the effect of all these variations on the rate of heart-beat.

(8) HEART-BEAT AND RESPIRATION

Examine a water-flea (Daphnia) under the microscope, and notice the heart beating. With a fine glass tube, bubble expired breath into the water containing the water-flea. Note that the heart-beat slows as the CO_2 content of the water increases.

(9) THE FLOW OF BLOOD

Anæsthetize a tadpole in a 2-per-cent. solution of ethyl urethane. When it ceases to move, lay it on a moist slide, and examine the tail under the low power. Observe the flow of blood in the capillaries. If the tadpole is young and still possesses external gills examine the flow of blood in these also.

(10) BLOOD SERUM

Blood plasma contains a substance which causes blood to clot. A portion of the plasma, however, does not clot, but remains fluid. This portion, which is called the **serum,** can be observed in a beaker of blood which has been left to clot.

CHAPTER XII
MOVEMENT AND SUPPORT

(1) COMPOSITION OF BONE

(*a*) Place a small bone on a tripod and heat strongly in a bunsen flame. After half an hour's heating allow it to cool, and compare its brittleness with that of an unheated bone.

(*b*) Leave a bone in dilute hydrochloric acid for some days and then wash it thoroughly in water and examine its flexibility.

(2) TENDONS

(*a*) Bend the hand downward and note the large tendons on the inner side of the wrist.

(*b*) Stretch the fingers and note the movement of tendons on the back of hand.

(3) Skeletons

Examine the skeletons of a fish, a bird, a rabbit, and a man. Note differences between the teeth of a sheep and those of a man.

(4) Vertebræ

Examine and draw the vertebræ of a man and those of a rabbit. Draw vertebræ from the cervical, thoracic, lumbar, sacral, and caudal regions, and also note and draw the atlas and axis vertebræ.

CHAPTER XIII

EXCRETION: THE REMOVAL OF WASTE

(1) Water in Breath

Breathe on a polished mirror. Note the condensation of water in the breath settling as droplets on the mirror.

(2) Amounts of Sweat and Urine

Notice that we pass urine more frequently and in greater quantities in cold weather. In hot weather we sweat more rapidly. Explain the relation between these facts.

(3) Composition of Urine

Evaporate some urine by heating in an evaporating dish. Notice what is left.

Test the residue with Nessler's reagent, which becomes orange in presence of ammonia. Test fresh urine, diluted with water, in the same way.

(4) Human Skin

Examine a prepared slide of human skin, and look for the sweat-glands. Note also the sebaceous glands, which supply an oily fluid to the hairs.

(5) Cooling by Evaporation

Damp your hand with water. Place it in a draught, and note the cooling effect. Repeat, using a few drops of ether. The cooling effect is greatly increased, because ether evaporates more quickly than water. In both cases expose untreated hand also to the same draught. (Why should one do this also?)

CHAPTERS XIV AND XV

THE NERVOUS SYSTEM; HORMONES AND GLANDS

(1) Response of Eyelids to Light or Movement

Suddenly shine a torch into the eyes of a friend. Try to prevent your eyes blinking when a hand is clapped just in front of them.

Observe the state of the pupil when a torch is shone in front of it.

(2) Effects of Light on Daphnia

Place a jar containing Daphnia in a darkened room; shine a bright light into the jar. Observe the response of the organisms. Leave the jar in darkness for an hour and then repeat the experiment. Compare the results obtained in the two experiments.

(3) Structure of Mammalian Eye

Obtain an eye of a sheep or other large animal from a butcher or slaughter-house. Cut it in half lengthwise. Examine and draw.

(4) Response of Seedlings to Light

Plant some oat grains or mustard or cress seeds in damp soil, near the surface. Three sets should be planted: one to be placed in darkness, one in a brightly illuminated place, lighted from every angle (out of doors in summer), and one in a place lighted from one side only. Observe the results after two days. Could differences in temperature alone have caused the resulting divergencies? How would you find out if temperature was the cause?

(5) Response of Seedlings to Gravity

Germinate broad beans in a mixture of equal parts of fine sand and sawdust. When the roots are about an inch long remove three beans. Mark their roots as in the experiment shown in Fig. 78.

Fix the beans, by means of long wires or pins, to the cork of a wide-necked bottle, the sides of which are lined with damp blotting-paper. The beans should be so fixed that the roots are horizontal.

If the apparatus is left overnight and examined the next day the roots will be found to have curved downward. The bending will have occurred in the region of active growth.

Why should the roots be kept in darkness?

(6) Response of a Plant Shoot to Gravity

Lay a potted plant on its side, point the plant shoot towards

the window, and leave the plant for a few days. Explain your result, and also explain why it was necessary to point the plant towards light to demonstrate this positive geotropism.

(7) Colour-changes of Prawns

Obtain a few live prawns. Constrict the eye-stalks of one prawn at the bases with fine forceps. Cut off the eyes with sharp scissors. After twenty-four hours the eyeless prawn will be much darker than the untreated animals. This will be especially noticeable if all the animals have been left on a white background.

Mash the two removed eye-stalks in five millilitres of sea-water, and then inject 0·1 millilitre of this fluid into the eyeless prawn. Note the change of colour. Examine the animal under a low-powered microscope.

CHAPTER XVI

GROWTH AND SIZE

(1) Period of Maximal Growth in Roots

A flat box is filled with sand and covered with cardboard. Before the cardboard is attached, some soaked beans are laid on the surface of the sand. The box is then stood on one of its edges. In this way seedlings with straight radicles are obtained.

Cotton is then taken, with which, after it has been soaked in Indian ink, a number of horizontal lines are marked on the radicle at intervals of one millimetre. The seeds are then attached by pins to a piece of cork, with their roots pointing downward, and are placed in a jar which has been lined with wet blotting-paper. After they have been forty-eight hours in a warm, dark place, examine them, and note the position of the lines on the radicle. (See Fig. 78.)

(2) Period of Maximal Growth in Shoots

Collect a number of young branches from the dog-rose, apple, or some other rapidly growing shoot. Measure the distance between successive nodes, and record this graphically.

(3) Influence of Principal Growing-point

Sow broad beans in fine soil near the surface. When the first leaf has developed cut off the growing tip. The bud in the axil of the leaf will thereupon grow, while if it also is removed the buds in the axils of the cotyledons will begin to grow.

(4) Rings of Annual Growth

Examine prepared slides of young and old woody stems.

(5) Cell-division

Examine prepared slides of sections of root-tips, stained to show stages of mitosis.

(6) Chromosomes

Crush some anthers of a flower[1] on a slide, add to them a drop of aceto-carmine, cover them with the cover-slip, and examine under high-power. The chromosomes should stain red.

CHAPTER XVII

PLANT REPRODUCTION

(1) Buds

Cut the terminal bud of a chestnut twig vertically in two. Examine the tightly packed leaves. Leave another chestnut twig in water indoors in the warmth, and study its development.

(2) A Comparison of Buds

Examine the opening buds of sycamore, lime, beech, ash, and horse chestnut in the spring. Compare these buds and record your results.

(3) Bulbs

Obtain the bulb of a tulip or an onion and the corm of a crocus. Cut each specimen in half and draw the cut surfaces. Explain the differences which you observe.

(4) Food Storage in Roots

Obtain specimens of the lesser celandine, draw its root-system, and explain what you observe.

(5) Fern Spores

Examine with a lens the lower surface of a fern frond, and look for sporangia. Remove some sporangia, and place them on a glass slide. Examine under the microscope.

(6) Fern Prothalli

Put some fine soil on a flat dish under a glass cover. Dampen it with water and sow on it some ripe fern spores. Keep the dish for three or four months, seeing that the soil is kept moist. Examine the prothalli which should form.

[1] *Lathyrus latifolius*, the everlasting pea, is a very suitable plant for this purpose (see *School Science Review*, XXIII (1942), No. 90, p. 227).

(7) STRUCTURE OF ANTHERS AND OVULES

Examine prepared slides of the transverse section of an anther and the longitudinal section of an ovule.

(8) EXAMINATION OF POLLEN-GRAINS

Examine the pollen-grains of various plants and record the differences. Stain with iodine or acetic methyl green to show the *two* nuclei. The grains will become more transparent by treatment with chloral hydrate or carbolic acid.

Types to examine: narcissus, hollyhock, broad bean, crocus, wallflower.

(9) GROWTH OF POLLEN-TUBES

Pollen-grains will form pollen-tubes if placed in solutions of sugar (5–20 per cent.) and left in darkness and warmth for a few hours. Stain as above and note the *three* nuclei. Look for streaming movements of the protoplasm.

(10) STRUCTURE OF SEEDS

Soak various seeds in water for twenty-four hours. Then cut open and examine them. The distinction between the following types of seed should be noticed:

(*a*) Endospermic (*i.e.*, where albumen is formed inside the embryo-sac)—onion, castor-oil seed, maize.

(*b*) Non-endospermic—bean, pea, vegetable marrow.

(11) FRUITS AND SEEDS

Collect a number of fruits and seeds. Make drawings of them, explain the nature of their parts, and discuss their probable means of dispersal. Identify the plants from which you gathered the seeds and record all your observations carefully in your note-book.

(12) FOOD MATERIALS IN FRUITS, SEEDS, ETC.

Test for foodstuffs in fruits, seeds, and organs of asexual reproduction by means of the methods outlined on p. 327.

Types for study: potato, apple, bean, castor oil, iris rhizome, wheat.

CHAPTER XVIII

ANIMAL REPRODUCTION

(1) ASEXUAL REPRODUCTION IN HYDRA

Collect water-weed from a slowly running stream and look for specimens of Hydra. If any are found, keep them in a well-

balanced aquarium and feed them with Daphnia. After some weeks asexually formed buds should appear.

(2) Regeneration

Obtain some flat-worms by placing a little meat on a dish in a running stream. Using a sterilized razor-blade, cut these animals as is shown in Fig. 148. Keep them for a week or so in a dish of pond-water and note the regeneration of lost parts.

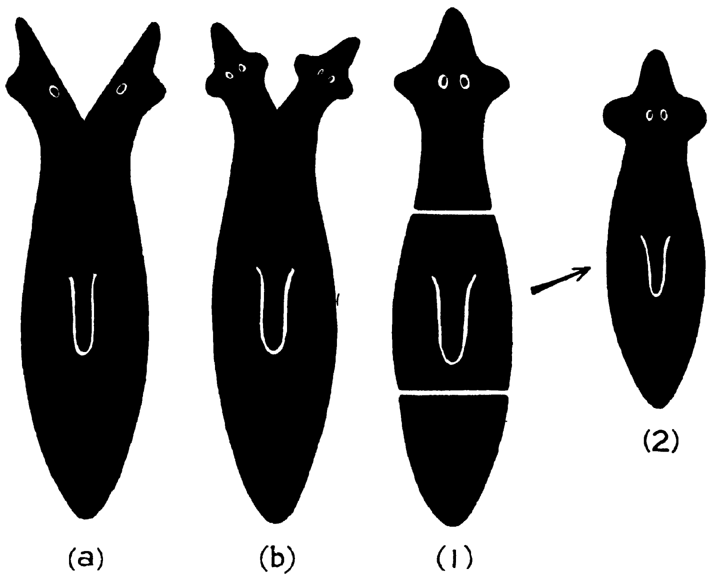

Fig. 148. Experiment of Regeneration

(*a*) A flat-worm, *Planaria*, with its head split by a single median cut; (*b*) the same animal some weeks later, when each half of the head has regenerated the missing portion, giving the animal two heads, (1) and (2) the central portion of a cut planarian regenerates both a head and a tail.

(3) Sperms and Eggs of the Frog

Place some pairing frogs in a tank containing a little water. Note that eggs pass from the body of the female frog and that the male frog deposits a grey fluid containing sperms on to the eggs. Collect some of the eggs and sperms and examine them.

(4) Sperms of the Earthworm

Open a freshly killed earthworm and place the contents of the seminal vesicles in 0·75 per cent. of salt solution. Examine these under the microscope and notice the sperms in various stages of development. Examine the contents of the spermathecæ and look for mature and active sperms.

(5) Sperms of the Snail

Living spermatozoa may be removed from the genital duct of the pond snail, Limnea, and examined in a drop of the snail's blood, under the high power of a microscope.

(6) Pregnancy in Mammals

Dissect a pregnant mouse or rabbit, and note the young in the uterus, each attached to the wall of the uterus by a placenta.

(7) The Food-value of Milk

Examine a chart showing the chemical composition of milk. Comment on the value of milk as a food for a baby. What other foods will the baby require to obtain a full supply of vitamins?

CHAPTER XX
BACTERIA AND VIRUSES

(1) Bacteria

Place a slice of potato in water, and after some days examine a drop of the water under the high power of a microscope. Notice the bacteria present.

(2) The Culture of Bacteria (*Preliminary Tests*)

Obtain some flat glass dishes called Petri dishes (or some test-tubes) and sterilize them by leaving them in an oven heated to 100° C. for twenty to thirty minutes. When they are cool pour in a hot solution of gelatine or of agar jelly. Cover the dishes at once. (Plug the mouths of the test tubes with cotton wool which has been just singed in a bunsen flame.) Various tests are now possible, using the sterile jelly, for example:

(*a*) Add a drop of milk (diluted one millilitre of milk to one hundred millilitres of sterile water) to melted gelatine.

(*b*) Breathe hard on the surface of the gelatine.

(*c*) Expose two dishes for five minutes in the classroom (*a*) before, and (*b*) immediately after, sweeping.

Bacteria should be tested for after all these processes have been completed. In all these tests keep an untreated control as a check.

(3) The Culture of Bacteria (*Advanced Tests*)

Consult a more advanced text-book for more detailed information on the culture of bacteria (*e.g.*, *Introduction to Laboratory Technique in Bacteriology*, M. Levine (Macmillan, 1933)).

(4) FLIES AND BACTERIA

Capture a fly, preferably one feeding on a refuse dump, and allow it to walk over a sterile dish of gelatine. Remove the fly, cover the dish, and examine after some days.

(5) PREPARED SLIDES OF BACTERIA

Examine prepared slides of bacteria.

CHAPTER XXI

PROTOZOA AND ALGÆ

(1) THE CULTURE OF PROTOZOA

Place a few leaves, taken from a pond or stream, in a jar of pond-water. Add a little hay. Leave for some weeks, examining some of the water at regular intervals under the high power.

(2) THE ACTION OF CILIA

Examine a fragment cut from the gill of a living fresh-water mussel under the high power of a microscope. The beating of cilia will be seen.

(3) FOOD VACUOLES IN PARAMECIUM

Examine living specimens of Paramecium which have been fed with Indian ink. Observe the food vacuoles.

(4) THE 'SKELETONS' OF PROTOZOA

Examine prepared slides of Foraminifera and Radiolaria.

(5) PARASITIC PROTOZOA

Extract some of the contents of the rectum of a dissected frog. Mount some of the material in a 0·75 per cent. salt solution. Examine under a microscope and look for living parasitic protozoa.

Examine prepared slides of malarial and trypanosome parasites.

CHAPTER XXII

THE FUNGI

(1) THE CULTURE OF FUNGI

Place some damp bread under a bell-jar and leave it for a few days, until it becomes covered with Mucor and other moulds. Examine these moulds under the high power of a microscope, and draw them.

(2) The Culture of Mucor

Examine the moulds which appeared in the previous experiment. Select a white mould, and lightly touch it with a clean paint-brush. Then touch the surface of sterile gelatine in a Petri dish with the same brush. Cover the dish quickly, and leave for a week or more. See whether Mucor has grown at the points touched by the brush.

(3) The Spores of a Mushroom

Remove the pileus from a mushroom and place it on some slightly moistened and gummed paper. Cover it with an inverted jam-jar, and leave for some hours. When the jar and pileus are then removed a 'print' of the spores will be left on the paper.

(4) Yeast and Carbon Dioxide

Place some yeast in a dilute sugar solution. Observe the production of CO_2 (Fig. 114).

(5) Saprolegnia

Leave a dead fly or some other insect in a jar of pond-water for some days. It may become covered with a white mould called Saprolegnia. Scrape off a little of this white, furry substance and examine it under a microscope.

CHAPTER XXIII
LIVING TOGETHER

(1) A Bee-hive

Examine frames containing honey and brood-cells taken from a bee-hive. Observe and comment on the construction of the hive.

(2) Pollen-baskets

Examine a worker bee which is visiting flowers in summer. Look for the pollen-baskets on the hind limbs.

(3) Colour-vision and Memory in Bees

Read the account of experiments on the colour-vision of bees described in *The Personality of Animals*, by H. Munro Fox (Pelican Books, 1940).

(4) A Formicary

You can construct a formicary, in order to observe the habits of ants, by enclosing two glass plates, about twelve inches square,

in a wooden frame, separated by an interval of a quarter of an inch or less. The interval should be filled by finely divided earth.

The apparatus is covered by a dark cloth when not under direct observation, and is surrounded by water or finely divided plaster to prevent the escape of the ants, which are placed in the earth when the apparatus is complete.

THE END

FILMS

The films included in the list below have been selected as examples of instructional films dealing with the subject-matter closely related to the text of this book; they represent merely a selection of the films issued by Gaumont British Instructional, Ltd.

F.595. *The Blow-fly.*
F.555. *The Life-cycle of a Plant* (the Lupin).
F.533. *Roots.*
F.714. *Cœlenterata* (polyps and jellyfish).
F.635. *Annelid Worms.*
F.800. *Crustacea.*
F.824. *Arachnida* (spiders and scorpions).
F.825. *Onychophora and Myriapoda* (centipedes and millipedes).
F.634. *Marine Sand Animals.*
F.689. *Animals of the Rocky Shore.*
F.661. *Interdependence of Pond Life.*
F.560. *How Plants Feed.*
F.528. *Breathing.*
F.625. *Blood.*
F.626. *Circulation.*
F.823. *The Fern.*
F.722. *Pollination.*
F.723, 724, 729, 828. *Methods of Seed Dispersal.*
F.545. *The Cabbage.*
F.548. *The Frog* (a life history).
F.614, F.697. *The Sea-urchin* (development).
F.792. *The Development of the Trout.*
F.726. *The Development of the Chick.*
F.559. *The Filter* (purification of water).
F.561. *Amœba.*
F.725. *Paramecium.*
F.698. *Fasciola* (the liver fluke).
F.601. *Wood Ants.*
F.551. *The Tortoiseshell Butterfly.*
F.821. *The Emperor Moth.*
F.544. *White Flies and Tomatoes.*

Gaumont British Instructional has also made the following films for the British Council, from whom they may be obtained: (1) *The Life-cycle of the Pin-mould*; (2) *The Life-cycle of Maize*; (3) *The Life-cycle of the Newt*; (4) *The Development of the Rabbit.*

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